Sensory Analysis of Foods of Animal Origin

© 2011 by Taylor and Francis Group, LLC

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Sensory Analysis of Foods of Animal Origin

Edited by
Leo M.L. Nollet
Fidel Toldrá



CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2011 by Taylor and Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number: 978-1-4398-4795-4 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (http://www.copyright.com/) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Sensory analysis of foods of animal origin / editors, Leo M.L. Nollet, Fidel Toldrá.
p. cm.
"A CRC title."
Includes bibliographical references and index.
ISBN 978-1-4398-4795-4 (hardcover : alk. paper)
1. Meat--Sensory evaluation. 2. Dairy products--Sensory evaluation. I. Nollet, Leo M. L., 1948- II. Toldrá, Fidel.

TX555.S46 2011
664'.9072--dc22 2010026747

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Downloaded From Vet-eBooks.com

Contents

Preface vii
Editors ix
Contributors xi

PART I MEAT

1 Color Measurements on Muscle-Based Foods 3
JOSÉ ANGEL PÉREZ-ALVAREZ AND JUANA FERNÁNDEZ-LÓPEZ

2 Measuring Meat Texture 15
MORSE B. SOLOMON, JANET S. EASTRIDGE, ERNIE W. PAROCZAY, AND BRIAN C. BOWKER

3 Techniques for Sampling and Identification of Volatile Compounds Contributing to Sensory Perception 39
SASKIA M. vAN RUTH

4 Sensory Descriptors 49
GEOFFREY R. NUTE

5 Sensory Perception 61
ROSIRES DELIZA AND MARIA BEATRIZ ABREU GLÓRIA

6 Sensory Aspects of Cooked Meats 87
NELCINDO NASCIMENTO TERRA, ROGÉRIO MANOEL LEMES DE CAMPOS, AND PAULO CÉZAR B. CAMPAGNOL

PART II PROCESSED MEATS AND POULTRY

7 Color Characteristics of Meat and Poultry Processing 101
JOSÉ ANGEL PÉREZ-ALVAREZ AND JUANA FERNÁNDEZ-LÓPEZ

8 Texture Analysis 121
SHAI BARBUT

9 Flavor of Meat Products 131
MÓNICA FLORES

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

10 Sensory Descriptors for Cooked Meat Products 147
JENNY E. HAYES

11 Sensory Descriptors for Dry-Cured Meat Products 173
MÓNICA FLORES

PART III FISH AND SEAFOOD PRODUCTS

12 Quality Assessment of Fish and Fishery Products by Color Measurement 199
REINHARD SCHUBRING

13 Instrumental Texture 229
ISABEL SÁNCHEZ-ALONSO, MARTA BARROSO, AND MERCEDES CARECHE

14 Aroma 243
JOHN STEPHEN ELMORE

15 Quality Index Methods 267
GRETHE HYLDIG, EMILÍA MARTINSDÓTTIR, KOLBRÚN SVEINSDÓTTIR, RIAN SCHELVIS, AND ALLAN BREMNER

16 Sensory Descriptors 285
GRETHE HYLDIG

17 Sensory Aspects of Heat-Treated Seafood 303
GRETHE HYLDIG

PART IV MILK AND DAIRY FOODS

18 Color 319
LAURENT DUFOSSÉ AND PATRICK GALAUP

19 Texture 341
KASIVISWANATHAN MUTHUKUMARAPPAN AND CHINNADURAI KARUNANITHY

20 Rheological Properties and Flavor Release 353
NATHALIE CAYOT

21 Flavor Formation 369
BARBARA D'ACAMPORA ZELLNER, PAOLA DUGO, GIOVANNI DUGO, AND LUIGI MONDELLO

22 Flavor 385
BARBARA D'ACAMPORA ZELLNER, PAOLA DUGO, GIOVANNI DUGO, AND LUIGI MONDELLO

23 Determination of Identity and Quality of Dairy Products 413
ROMDHANE KAROUI

Index 435

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Preface

People eat foods in general, and consequently, foods of animal origin, with their sensory organs. Sensory quality is a basic factor that influences consumers in purchasing food. Thus, color, aroma, taste, and texture, as well as the overall appearance are important factors that affect consumers' preferences and influence the acceptability of the food. It is therefore worth the effort to identify and quantify these sensory quality attributes.

This book, *Sensory Analysis of Foods of Animal Origin*, is divided into four parts: Part I deals with meat, Part II with processed meats and poultry, Part III with fish and seafood products, and Part IV with milk and dairy products.

In all four parts, selected chapters describe the analysis of color and texture of different foods of animal origin as well as recent advances in texture measurement (Chapters 1, 2, 7, 8, 12, 13, 18, 19, and 20). This is followed by a discussion on techniques for sampling and the identification of volatile compounds (Chapters 3, 9, 14, 21, and 22). A detailed description of the sensory aspects (sensory descriptors, sensory perception, and aroma) of these kinds of food is provided next (Chapters 4 through 6, 10, 11, 16, and 17). Finally, some chapters deal with quality index methods (Chapters 15 and 23).

In each chapter, the authors start with a discussion of the parameter in question. Where necessary, sample preparation methods are reviewed in depth. This is followed by a discussion and assessment of the sensory qualities, or a detailed overview of different detection methods. Finally, a brief summary covers the presence of these parameters in different end products, regions, and countries.

All the chapters have been written by renowned scientists who are experts in their fields of research. Only the most recent techniques and related literature have been dealt with.

We would like to thank all our colleagues and contributing authors for their efforts in producing this excellent work.

> What you leave behind is not what is engraved in stone monuments, but what is woven into the lives of others. (Pericles)

Leo M.L. Nollet
Fidel Toldrá

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Editors

Dr. Leo M.L. Nollet is an editor and associate editor of several books. He has edited the first and second editions of *Food Analysis by HPLC* and the *Handbook of Food Analysis* (which is a three-volume book) for Marcel Dekker, New York (now CRC Press of Taylor & Francis Group). He has also edited the third edition of the book, *Chromatographic Analysis of the Environment* (CRC Press, Boca Raton, Florida) and the second edition of the *Handbook of Water Analysis* (CRC Press, Boca Raton, Florida) in 2007. He coedited two books with F. Toldrá that were published in 2006: *Advanced Technologies for Meat Processing* (CRC Press, Boca Raton, Florida) and *Advances in Food Diagnostics* (Blackwell Publishing, New York). He also coedited *Radionuclide Concentrations in Foods and the Environment* with M. Pöschl in 2006 (CRC Press, Boca Raton, Florida).

Dr. Nollet has coedited several books with Y. H. Hui and other colleagues, including the *Handbook of Food Product Manufacturing* (Wiley, New York, 2007); the *Handbook of Food Science, Technology and Engineering* (CRC Press, Boca Raton, Florida, 2005); and *Food Biochemistry and Food Processing* (Blackwell Publishing, New York, 2005). He has also edited the *Handbook of Meat, Poultry and Seafood Quality* (Blackwell Publishing, New York, 2007).

Dr. Nollet has worked on the following six books on analysis methodologies with F. Toldrá for foods of animal origin, several of these books have already been published by CRC Press, Boca Raton, Florida:

Handbook of Muscle Foods Analysis
Handbook of Processed Meats and Poultry Analysis
Handbook of Seafood and Seafood Products Analysis
Handbook of Dairy Foods Analysis
Handbook of Analysis of Edible Animal By-Products
Handbook of Analysis of Active Compounds in Functional Foods

He has also worked with Professor H. Rathore on the *Handbook of Pesticides: Methods of Pesticides Residues Analysis*, which was published by CRC Press, Boca Raton, Florida, in 2009.

Dr. Fidel Toldrá is a research professor in the Department of Food Science at the Instituto de Agroquímica y Tecnología de Alimentos (CSIC), Valencia, Spain, and serves as the European editor of *Trends in Food Science & Technology*, the editor in chief of *Current Nutrition & Food Science*, and as a member of the Flavorings and Enzymes Panel at the European Food Safety Authority. In recent years, he has served as an editor or associate editor of several books. He was the editor of *Research Advances in the Quality of Meat and Meat Products* (Research Signpost,

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Trivandrum, Kerala, India, 2002) and the associate editor of the *Handbook of Food and Beverage Fermentation Technology* and the *Handbook of Food Science, Technology and Engineering* published in 2004 and 2006, respectively, by CRC Press, Boca Raton, Florida. He coedited two books with L. Nollet that were published in 2006: *Advanced Technologies for Meat Processing* (CRC Press, Boca Raton, Florida) and *Advances in Food Diagnostics* (Blackwell Publishing, New York). Both he and Nollet are also associate editors of the *Handbook of Food Product Manufacturing* published by John Wiley & Sons, New York, in 2007. He has also edited *Meat Biotechnology* and *Safety of Meat and Processed Meat* (Springer, Berlin, Germany, 2008 and 2009, respectively) and has authored *Dry-Cured Meat Products* (Food & Nutrition Press—now Wiley-Blackwell, New York, 2002).

Dr. Toldrá has worked on the following six books on analysis methodologies with L. Nollet for foods of animal origin, several of these books have already been published by CRC Press, Boca Raton, Florida:

Handbook of Muscle Foods Analysis
Handbook of Processed Meats and Poultry Analysis
Handbook of Seafood and Seafood Products Analysis
Handbook of Dairy Foods Analysis
Handbook of Analysis of Edible Animal By-Products
Handbook of Analysis of Active Compounds in Functional Foods

Dr. Toldrá was awarded the 2002 International Prize for Meat Science and Technology by the International Meat Secretariat. He was elected as a fellow of the International Academy of Food Science & Technology in 2008 and as a fellow of the Institute of Food Technologists in 2009. He recently received the 2010 Distinguished Research Award from the American Meat Science Association.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Contributors

Shai Barbut
Department of Food Science
University of Guelph
Guelph, Ontario, Canada

Marta Barroso
Consejo Superior de Investigaciones Científicas
Instituto del Frío
Madrid, Spain

Brian C. Bowker
United States Department of Agriculture
Agriculture Research Service
Animal and Natural Resources Institute
Beltsville, Maryland

Allan Bremner
Allan Bremner and Associates
Mount Coolum, Queensland, Australia

Paulo Cézar B. Campagnol
Faculdade de Engenharia de Alimentos
Departamento de Tecnologia de Alimentos
Universidade Estadual de Campinas
Campinas, São Paulo, Brazil

Rogério Manoel Lemes de Campos
Departamento de Tecnologia e Ciência dos Alimentos
Centro de Ciências Rurais
Universidade Federal de Santa Maria
Santa Maria, Rio Grande do Sul, Brazil

Mercedes Careche
Consejo Superior de Investigaciones Científicas
Instituto del Frío
Madrid, Spain

Nathalie Cayot
Unité Mixte de Recherche Flavonoid
Etablissement national d'enseignement supérieur agronomique de Dijon
Institut National de la Recherche Agronomique
Dijon, France

Rosires Deliza
Embrapa Agroindustria de Alimentos
Rio de Janeiro, Brazil

Laurent Dufossé
Laboratoire de Chimie des Substances Naturelles et des Sciences des Aliments
Ecole Supérieure d'Ingénieurs en Développement Agroalimentaire Intégré
Université de la Réunion
La Réunion, France

Giovanni Dugo
Facoltà di Farmacia
Dipartimento Farmaco-chimico
Università di Messina
Messina, Italy

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Paola Dugo
Facoltà di Farmacia
Dipartimento Farmaco-chimico
Università di Messina
Messina, Italy

Janet S. Eastridge
United States Department of Agriculture
Agriculture Research Service
Animal and Natural Resources Institute
Beltsville, Maryland

John Stephen Elmore
Department of Food Biosciences
University of Reading
Reading, United Kingdom

Juana Fernández-López
Departamento de Tecnologia Agroalimentaria
Escuela Politécnica Superior de Orihuela
Miguel Hernández University
Alicante, Spain

Mónica Flores
Department of Food Science
Spanish National Research Council
Agrochemistry and Food Technology Institute
Valencia, Spain

Patrick Galaup
Laboratoire ANTiOX
Université de Bretagne Occidentale
Quimper, France

Maria Beatriz Abreu Glória
Faculdade de Farmácia
Laboratorio de Bioquímica de Alimentos
Departamento de Alimentos
Universidade Federal de Minas Gerais
Belo Horizonte, Brazil

Jenny E. Hayes
Ashtown Food Research Centre
The Irish Agriculture and Food Development Authority
Dublin, Ireland

Grethe Hyldig
Aquatic Process and Product Technology
National Institute of Aquatic Resources (DTU Aqua)
Technical University of Denmark
Lyngby, Denmark

Romdhane Karoui
Unité de Recherche
Typicité des Produits Alimentaires
Ecole nationale des ingenieurs des travaux agricoles de Clermont Ferrand
Lempdes, France

Chinnadurai Karunanithy
Agricultural and Biosystems Engineering
South Dakota State University
Brookings, South Dakota

Emilía Martinsdóttir
Matís
Iceland Food Research
Reykjavík, Iceland

Luigi Mondello
Facoltà di Farmacia
Dipartimento Farmaco-chimico
Università di Messina
Messina, Italy

Kasiviswanathan Muthukumarappan
Agricultural and Biosystems Engineering
South Dakota State University
Brookings, South Dakota

Geoffrey R. Nute
Division of Farm Animal Science
School of Vertinary Science
University of Bristol
Langford, United Kingdom

Ernie W. Paroczay
United States Department of Agriculture
Agriculture Research Service
Animal and Natural Resources Institute
Beltsville, Maryland

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

José Angel Pérez-Alvarez
Departamento de Tecnologia Agroalimentaria
Escuela Politécnica Superior de Orihuela
Miguel Hernández University
Alicante, Spain

Saskia M. van Ruth
RIKILT
Institute of Food Safety
Wageningen University and Research Centre
Wageningen, the Netherlands

Isabel Sánchez-Alonso
Consejo Superior de Investigaciones Científicas
Instituto del Frío
Madrid, Spain

Rian Schelvis
Institute for Marine Resources and Ecosystem Studies
Wageningen University and Research Centre
IJmuiden, the Netherlands

Reinhard Schubring
Department of Safety and Quality of Milk and Fish Products
Federal Research Institute for Nutrition and Food
Max Rubner-Institut
Hamburg, Germany

Morse B. Solomon
United States Department of Agriculture
Agriculture Research Service
Animal and Natural Resources Institute
Beltsville, Maryland

Kolbrún Sveinsdóttir
Matís
Iceland Food Research
Reykjavik, Iceland

Nelcindo Nascimento Terra
Departamento de Tecnologia e Ciência dos Alimentos
Centro de Ciências Rurais
Universidade Federal de Santa Maria
Santa Maria, Rio Grande do Sul, Brazil

Barbara d'Acampora Zellner
Facoltà di Farmacia
Dipartimento Farmaco-chimico
Università di Messina
Messina, Italy

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

MEAT

1

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 1

Color Measurements on Muscle-Based Foods

José Angel Pérez-Alvarez and Juana Fernández-López

Contents

1.1 General Aspects of Color 3
1.1.1 Color Attributes 3
1.1.1.1 Appearance 4
1.1.1.2 Color as Quality Parameter 4
1.2 Color Measurement 5
1.2.1 Objective Methods 6
1.2.1.1 Reflectance Measurements 7
1.2.1.2 Near-Infrared Analysis 9
References 10

1.1 General Aspects of Color

The first impression that a consumer receives concerning a food product is established visually, and among the properties observed are color, form, and surface characteristics. The power of color for food is not in doubt. Color appearance, color contrast, and color difference in muscle-based foods can have a significant effect on an individual's moods and feelings, and food technologists can exploit these effects.

1.1.1 Color Attributes

Color is the main aspect that defines a food's quality, and a product may be rejected simply because of its color, even before other properties, such as aroma, texture, and taste, can be evaluated [1].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

All muscle-based foods possess a number of visually perceived attributes, all of which contribute to their color and appearance as well as to their overall quality. According to Lozano [2], the appearance, can be divided into three different categories: color, cesia, and spatial properties or spatiality. Color is related to optical power spectral properties of the stimulus detected by observers. Cesia includes transparency, translucence, gloss, luster, haze, lightness, opacity, matte and is related to the properties of reflecting, transmitting, or diffusing light by foods as evaluated by human observation. Spatial properties are divided into two main groups: (i) modes of appearance in which color is modified depending on the angle of observation relative to the angle of light incidence, such as metallic, pearlescent, or iridescent materials, and (ii) modes of appearance related to optical properties of surfaces or objects in which effects of ordered patterns (textures) or finishing characteristics of food (roughness, polish, etc.) may be apparent.

1.1.1.1 Appearance

The overall appearance of an object consists of visual structure, surface texture, and distributions of color, gloss, and translucency. It comprises the visual images within the observer. These images are controlled by viewer-dependent variables and scene-dependent variables. The first consists of the viewer's individual visual characteristics, upbringing and preferences, and immediate environment. The second consists of the physics of the constituent materials and their temporal properties combined with the way these are put together, as well as the scene illumination, that is, the light and shade as they define the volume and texture of the scene. The model considers the buildup of the appearance image [3]. As regards the specific characteristics that contribute to the physical appearance of meat, color is the quality that most influences consumer choice [4]. This is why the appearance (optical properties, physical form, and presentation) of meat products at the sales point is of such importance for the meat industry [5].

1.1.1.2 Color as Quality Parameter

The relation between meat color and quality has been the subject of study since the 1950s—since, indeed, Urbain [6] described how consumers had learned through experience that the color of fresh meat is bright red and any deviation from this color (nonuniform or anomalous coloring) is unacceptable [7]. The color of fresh meat and associated adipose tissue is, then, of great importance for its commercial acceptability, especially in the case of beef and lamb [8] and in certain countries such as the United States and Canada; there have been many studies attempting to identify the factors controlling its stability. Adams and Huffman [9] affirmed that consumers relate a meat's color with its freshness. In poultry, the consumers of many countries also associate the meat color with the way in which the animal was raised (intensive or extensive) and fed (cereals, animal feed, etc.) [10,11].

The color of foods greatly influences consumers' preferences [12,13]. Color as a quality factor in meat can be appreciated in different ways in different countries. For example, in Denmark, pork meat color has the fifth place among consumers' purchase decision criteria [14]. In the U.S. and Mexico, chicken skin color plays a significant role in the acceptance of chicken [15]. In the Balkans, visual impression when choosing young beef in retail stores was most important for the average consumer. In these countries the survey found color to be the deciding factor (red pink color was desirable) [16]. Sensorial quality, especially color and appearance [17], of meat can be affected by internal and external factors. For example, in poultry, if carbohydrate supplements are used prior to slaughter, producers should notify processing plant officials so that inspectors do not interpret light livers as an abnormal physiological state [18].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Food technologists, especially those concerned with the meat industry, have a special interest in the color of food for several reasons: first, because of the need to maintain a uniform color throughout processing; second, to prevent any external or internal agent from acting on the product during its processing, storage, and display; third, to improve or optimize a product's color and appearance; and, last, to bring the product's color into line with what the consumer expects [19].

In simple words, the color of meat is determined by the pigments present in the meat. These can be classified into four types: biological (carotenes and hemopigments), which are accumulated or synthesized in the organism antemortem [5]; pigments produced as a result of damage during manipulation or inadequate processing conditions; pigments produced postmortem (through enzymatic or nonenzymatic reactions) [20]; and, finally, those resulting from the addition of natural or artificial colorants [21].

The color also provides information about raw materials [22,23], processing technologies [24], storage conditions [25], shelf life [26], and defects [27]. As a quality parameter, color has been widely studied at slaughter [28] and in fresh meat [29–31] and cooked products [32–34]. Dry-cured meat products have received less attention [25,35,36] because in this type of product color formation takes place during the different processing stages [24,37]; recently, new hem pigment has been identified in this type of product [38–40].

From a practical point of view, color plays a fundamental role in the animal production sector, especially in meat production (beef and poultry, primarily) [41–44]; thus, supplementation of swine diets with 80 mg/kg of manganese may improve pork color and retard discoloration during retail display [45]. Ponsano et al. [46] found that *Rhodocyclus gelatinosus* supplementation resulted in more yellow breast skin and increased darkening and color purity of breast and thigh skins. Also, the consumer can evaluate beef fat as undesirable if it has yellow or dark color, or is excessive glossy or lustrous [44].

In many countries of the European Union (e.g., Spain and Holland), paleness receives a wholesale premium. The poultry sector is also affected by color characteristics, according to Zhang et al. [45]; skin color is used as indicator for chicken sex.

Color can also be used as an important tool by slaughter plant food inspectors. Trampel et al. [18] determined that livers from full-fed birds were lighter in color than normal, and consequently a significant number of chicken carcasses can be condemned for human consumption because they are associated with higher hepatic lipid concentrations.

There are some studies in which technological parameters and color coordinates are related. Pale, soft, exudative (PSE) meat is a growing problem in the poultry industry (characterized by rapid postmortem pH decline). The low pH condition while the body temperature has not yet chilled leads to protein denaturation, causing pale color and reduced water-holding properties. The water loss and protein damage from the PSE condition may impact the visible muscle properties [46]. Thus, Fraqueza et al. [47] stated that PSE and dark turkey meat quality can be defined by lightness (color coordinate: L^*) and pH, thus, dark turkey meat showed $L^* \leq 44$ and $pH_{24} > 5.8$, while PSE turkey meat showed $L^* \geq 50$ and $pH_{24} < 5.8$. Fasone and Priolo [48] stated that in ostrich meat, meat lightness (L^*) was strongly affected by stress; in fact, the color of meat from stressed ostriches was darker than meat from nonstressed birds (34.30 versus 38.10, respectively).

1.2 Color Measurement

The color of foods can be defined as the interaction of a light, an object, an observer, and the surroundings of the food. Recently, the International Commission on Illumination [49] described how background can influence the appreciation of color.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

1.2.1 Objective Methods

Optical methods have the advantage of being nondestructive, fast, inexpensive, and are considered suitable for online measurement. The color of foods can be studied in two main ways: chemically by analyzing the pigments present or physically by measuring the interaction of light. Color necessarily requires a light source that illuminates an object, which, in turn, modifies the light and reflects (or transmits) it to an observer. The observer senses the reflected light, and the combined factors provide the stimulus that the brain converts into our perception of color, a property that has three quantitatively definable dimensions: hue, chroma, and lightness [50].

Several methods are available for objectively measuring the color of foods, some of which depend on the extraction of pigments from food products followed by spectrophotometric determination of pigment concentration [51,52]. However, since such pigment extraction methods are time-consuming and tedious, some researchers have sought simpler methods of color measurement. For example, several methods measure the light reflected from the surface of foods. There are also tabulated coefficients of various objective values that are correlated with panel scores [53]. These objective values consist of numerous combinations of percentage reflectance values and tristimulus values such as Hunter Lab [54], CIE XYZ, Munsell hue, chroma, and value or CIELAB [19]. The use of this color space was adopted as an internal standard. Thus, in many countries the use of this color space is related to quality control, using D_{65} as illuminant and 10° as standard observer [55]. L^* is a measure of lightness in which 0 equals black and 100 equals white. High, positive values of a^* indicate redness; large, negative values indicate greenness; b^* values indicate yellowness to blueness. In Table 1.1, CIELAB color coordinates of different raw materials used for meat products elaboration process are shown.

Table 1.1 Color Coordinates (*L [Lightness], *a** [Redness], and *b** [Yellowness]) of Different Raw Materials Used for Meat Products Elaboration Process**

Raw Material	*L**	*a**	*b**
Pork lard	65.04	2.91	5.28
Pork streaky bacon	62.18	3.65	4.68
Pork dewlap	63.12	3.88	3.60
Chicken breast	62.11	0.99	3.55
Chicken thigh	59.95	1.11	3.98
MDCM	43.42	18.79	13.68
Pork lean meat	42.67	8.76	3.96
Beef stifle	32.42	15.59	5.11
Pork heart	37.27	13.09	7.37
Pork lung	48.25	22.99	14.17

Note: MDCM: mechanically deboned poultry meat.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The univariate correlation between a^* and myoglobin concentration was 0.92. However, Lindahl et al. [56] in a recent study reported that a^* values explained more than 90% of the variation in pigment content and form of pork muscles. Another study demonstrated that L^* value was the instrumental value most highly correlated with subjectively assessed color when this was based on the Japanese Color Standards [57].

1.2.1.1 Reflectance Measurements

Diffuse reflectance measures photons that have survived absorption, been scattered diffusely in meat, and eventually escaped from the meat surface. Hence, the conventional absorbance is the combined result of the absorbing and scattering effects and is different from the derived absorption coefficient, which is independent of scattering. Absorbance cannot provide an accurate absorption spectrum because the scattering effect is not excluded. Similarly, the scattering coefficients are independent of sample chemical compositions and are solely determined by sample ultrastructure properties [58]. Color characteristics of dry-cured meat products are measured by reflectance values, which consist of indices and differences of reflectance at different wavelengths [59].

Myoglobin absorbs light in the ultraviolet region and through practically the complete visible region of light [60]. Metmyoglobin (MMb), oxymyoglobin (OMb), nitrosomyoglobin (NOMb), and deoxymyoglobin (DMb) have maximum absorbances (>400 nm) at about 410, 418, 419, and 434 nm, respectively [61]. The absorbance is typically much weaker at higher wavelengths (500–600 nm). Above 500 nm, myoglobin (OMb and NOMb) have absorption maxima at around 545 and 585 nm [61]. The NOMb complex maintains myoglobin in the ferrous state, but this is somewhat unstable and can be displaced and oxidized if stored with excess oxygen and light [62].

Objective color measurements may refer to several properties or various ratios or color difference indices [50]. By summarizing all the reflected colors (wavelengths) and expressing them as one color [63], the color a consumer sees can generally be described in one or two words, which indicate the main color and its shade. However, color measurements, whether descriptive or specific, must be made as carefully as other measurements [50].

Correlations between visual assessment and instrumental color measurement of muscle-based foods are not very high, generally due to both the technique and measurement conditions [25].

Rapid screening techniques to determine quality characteristics of meat are of great interest for both industry and consumers. Reflectance measurements closely relate to what the eye and brain see. This is a good method for examining the amount and chemical state of myoglobin in meat *in situ*. This method is also able to provide a procedure for estimating the percentages of myoglobin forms on the surface of meat. With this method, repeated measurements over time can be made on the same sample. In addition, the procedure is rapid and relatively easy. Reflectance measurements are affected by muscle structure, surface moisture, fat content, additives, and pigment concentrations [64]. Also, tissue structures are associated with the light-scattering properties of meat. In beef, light scattering could potentially be used as an indicator of beef tenderness [65].

Thus, the increase in reflectance values could be related to such factors as water-holding capacity (WHC). Its diminution, caused by falling pH, might cause the meat structure to close up, driving out the intracellular water, thus hindering light penetration into the myofibrils and increasing light scattering. Feldhusen [66] reported that this effect on reflectance values could be related to the sarcoplasmic protein denaturation and precipitation on the myofibrils, resulting in increased light scattering and less light penetration [25,64].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Reflectance spectra also were used to evaluate growth rates [67], detect poultry feces and ingesta [68] or fecal contamination of chicken carcasses [69], determine the use of nitrite in cooked meat products such as bologna type, etc. Swatland [70] reported that the use of nitrite was associated with lower reflectance at 400 and 410 nm, and with higher reflectance at 430 and 440 nm and from 600 to 700 nm.

Reflectance values of different myoglobin states (DMb, MMb, and OMb) can be equal at several wavelengths (isobestic points). Thus, myoglobin forms can be quantified by this method. Swatland [70] also found isobestic points at 580 nm in samples with and without use of nitrites. According to Snyder [71], several isobestic points are found in beef at 474, 525, 572, and 610 nm. All myoglobin states can be stated at 525 nm in beef. This behavior was also found in pork by Fernández-López et al. [72] and by Navarro [73]. This author also found more isobestic wavelengths for chicken meat and mechanically deboned poultry recovered meat (430, 440, 450, 460, 510, 560, 570, 610, 690 nm) than for beef and pork. In Figures 1.1 and 1.2, reflectance spectra of the different myoglobin states of tuna fish dark muscle and pork shoulder meat, respectively, can be observed. In tuna dark muscle, there are no differences in several wavelengths between OMb and DMb myoglobin states reflectance spectra.

Liu et al. [74] found that intensities of two visible bands at 445 and 560 nm increase with the storage temperature, possibly indicating a color change due to frozen storage. The reduction of spectral intensities probably indicate water loss and compositional alterations during the freeze-thaw process as well as the tenderization development in muscle storage. Chao et al. [75] determined that reflectance spectra in the range of 400–867 nm can be used for veterinarians to select wholesome and unwholesome carcasses.

Irie [44] reported that the main factors affecting bovine fat appearance are carotene concentration and hemoglobin concentration, which affect yellowness and redness, respectively. Also, the chemical state of hemoglobin and the translucency of fat affected the color and percentage reflectance or darkness of beef fat.

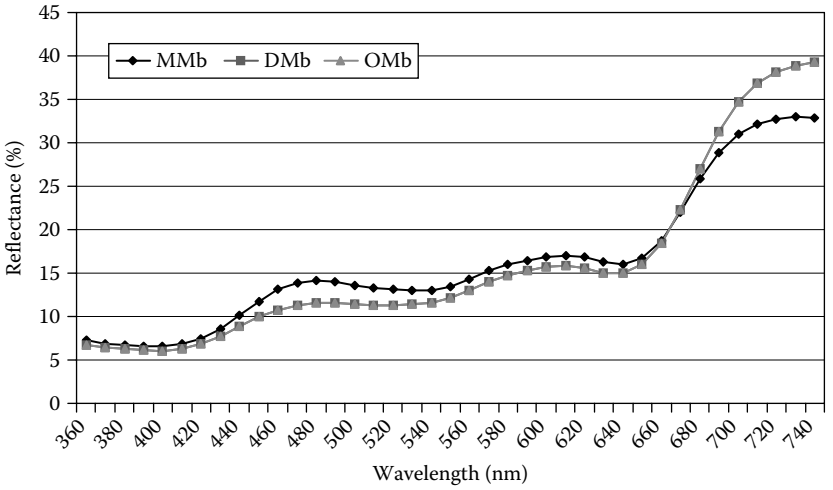


Figure 1.1 Reflectance spectra (360–740 nm) of different myoglobin states (OMb, oxymyoglobin; DMb, deoxymyoglobin; MMb, metmyoglobin) of tuna dark muscle (thynnus thynnus).

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

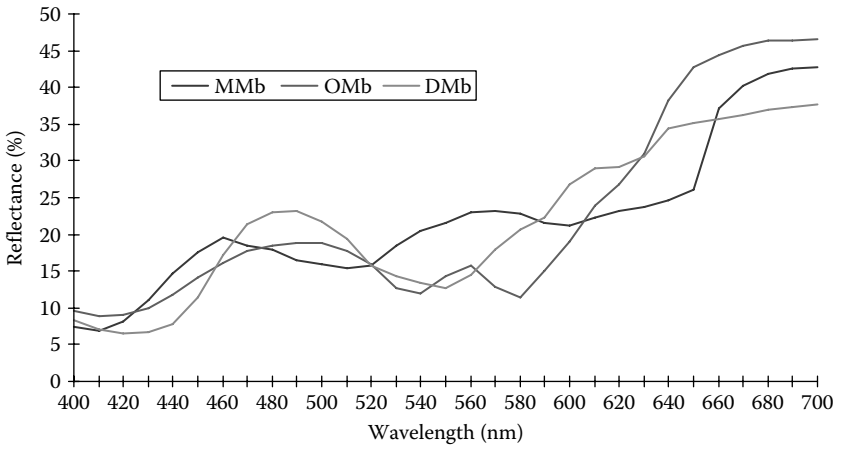


Figure 1.2 Reflectance spectra (400–700 nm) of different myoglobin states (OMb, oxymyoglobin; DMb, deoxymyoglobin; MMb, metmyoglobin) of pork meat.

1.2.1.2 Near-Infrared Analysis

Near-infrared (NIR) technology by spectral analysis provides complete information about the molecular bonds and chemical constituents in a scanned sample. Optical devices coupled to computers offer potentially very fast data acquisition that may permit decision-making on meat eating quality, albeit from a selected small surface area only [76].

When near-infrared reflectance (NIR) spectroscopy is used, it can be useful for quality control. This technique can predict the chemical composition of poultry meat and possibly some dietary treatments applied to the chickens [77]. Recent studies have therefore concentrated on looking for applications for this technique [78,79]. There is substantial interest in using NIR online to predict chemical parameters in the meat industry and to augment existing video image scanning and analysis (VISA) technology systems [80]. New VISA systems [81,82] provide a noninvasive method operating at normal abattoir chain speeds and enable automatic acquisition of data on carcasses using the side and back view. However, these systems cannot classify on the basis of meat quality and therefore need to be augmented with other suitable systems to measure traits related to meat eating quality. Post-rigor drip loss and WHC during storage can be predicted adequately by NIRS, which can determine WHC specifically, rather than the occurrence of PSE, using techniques such as near-infrared spectroscopy [83]. Also, this technique can be used to predict beef tenderness [84–88].

The USDA Agricultural Research Service has developed a method using a hyperspectral imaging system to detect feces (from duodenum, ceca, and colon) and ingesta on poultry carcasses. The method involves first the use of multivariate data analysis of visible and near-infrared (Vis/NIR) reflectance spectra of fecal and uncontaminated skin samples for classification of contaminants [68].

Myoglobin content varies with species and with fiber type within a particular species. For example, a type I muscle such as beef masseter contains more myoglobin, while a large type IIB pork muscle such as glutens medius contains little myoglobin. Beef latissimus dorsi is an intermediate muscle in myoglobin content.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

However, some authors [89,90] have found evidence for the possibility of estimating myoglobin in meat samples using the visible region (400–800 nm) of the spectrum. This would be feasible due to the different forms of myoglobin in the meat samples (OMb, DMb, and MMb), thus giving rise to different colors (bright red, purple, and brown, respectively).

References

1. Pérez-Alvarez, J.A., Fernández-López, J., and Sayas-Barberá, M.E. Fundamentos físicos, químicos, ultraestructurales y tecnológicos en el color de la carne. In *Nuevas tendencias en la tecnología e higiene de la industria cárnica*, eds. M.R. Rosmini, J.A. Pérez-Alvarez, and J. Fernández-López, 51–71. Elche: Universidad Miguel Hernández. 2000.
2. Lozano, D. A new approach to appearance characterization. *Color Res Appl* 31(3):164–167. 2006.
3. Hutchings, J.B. The perception and sensory assessment of colour. In *Colour in food, improving quality*, ed. D.B. MacDougall, 9–32. Cambridge: Woodhead Publishing. 1999, 2002.
4. Krammer, A. Use of color measurements in quality control of food. *Food Technol* 48(10):62–71. 1994.
5. Lanari, M.C. et al. Pasture and grain finishing affect the color stability of beef. *J Food Sci* 67: 2467–2473. 2002.
6. Urbain, M.W. Oxygen is key to the color of meat. *Nat Prov* 127:140–141. 1952.
7. Diestre, A. Principales problemas de la calidad de la carne en el porcino. *Alimentación Equiposy Tecnología* 98:73–78. 1992.
8. Conforth, D. Colour—its basis and importance. In *Advances in meat research*, eds. A.M. Pearson, and T.R. Dutson, 34–78. London: Chapman Hall. 1994.
9. Adams, D.C. and Huffman, R.T. Effect of controlled gas atmospheres and temperature on quality of packaged pork. *J Food Sci* 37:869–872. 1972.
10. De Marchi, M. et al. Carcass characteristics and qualitative meat traits of the Padovana breed of chicken. *Int J Poult Sci* 4:233–238. 2005.
11. Pelicano, E.R.L. et al. Carcass and cut yields and meat qualitative traits of broilers fed diets containing probiotics and prebiotics. *Rev Bras Ciencia Avicola* 7(3):169–175. 2005.
12. Calvo, C., Salvador, A., and Fiszman, S.M. Influence of colour intensity on the perception of colour and sweetness in various fruit flavoured yoghurts. *Eur Food Res Technol* 213:99–103. 2001.
13. Hutchings, J.B. *Food colour and appearance* (2nd ed). Gaithersburg, MD: Aspen Publishers. 1999.
14. Bryhni, E.A. et al. Consumer perceptions of pork in Denmark, Norway and Sweden. *Food Qual Pref* 13:257–266. 2002.
15. Castaneda, M.P., Hirschler, E.M., and Sams, A.R. Skin pigmentation evaluation in broilers fed natural and synthetic pigments. *Poult Sci* 84(1):143–147. 2005.
16. Ostojic, D. et al. Criteria of consumers when purchasing beef in retail stores: position of beef compared to other meat types, reasons and frequency of its use in everyday nutrition and preparation methods. *Biotechnol Anim Husbandry* 22(3/4):45–53. 2006.
17. Brewer, M.S. and Mckeith, F.K. Consumer-rated quality characteristics as related to purchase intent of fresh pork. *J Food Sci* 64:171–174. 2006.
18. Trampel, D.W. et al. Preharvest feed withdrawal affects liver lipid and liver color in broiler chickens. *Poult Sci* 84(1):137–142. 2005.
19. Pérez-Alvarez, J.A. Color. In *Ciencia y tecnología de carnes*, eds. Y.H. Hui, I. Guerrero and M.R. Rosmini, 161–198. México: Limusa Noriega Editores. 2006.
20. Montero, P., Ávalos, A., and Pérez-Mateos, M. Characterization of polyphenoloxidase of prawns (*Penaeus japonicus*). Alternatives to inhibition: additives and high pressure treatment. *Food Chem* 75:317–324. 2001.
21. Fernández-López, J. et al. Effect of paprika (*Capsicum annum*) on color of Spanish-type sausages during the resting stage. *J Food Sci* 67:2410–2414. 2002.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

22. Pérez-Alvarez, J.A. et al. Utilización de vísceras como materias primas en la elaboración de productos cárnicos: güeña. *Alimentaria* 291:63–70. 1998a.
23. Pérez-Alvarez, J.A. et al. Caracterización de los parámetros de color de diferentes materias primas usadas en la industria cárnica. *Eurocarne* 63:115–122. 1998b.
24. Pérez-Alvarez, J.A. et al. Chemical and color characteristics of "Lomo embuchado" during salting seasoning. *J Muscle Food* 8(4):395–411. 1997.
25. Pérez-Alvarez, J.A. Contribución al estudio objetivo del color en productos cárnicos crudo-curados. [PhD Thesis]. Valencia, Spain: Universidad Politécnica de Valencia. 1996.
26. Fernández-López, J. et al. Physical, chemical and sensory properties of bologna sausage made with ostrich meat. *J Food Sci* 68:1511–1515. 2003.
27. Ferrer, O.J., Otwell, W.S., and Marshall, M.R. Effect of bisulfite on lobster shell phenoloxidase. *J Food Sci* 54(2):478–480. 1989.
28. Bozek, R. and Juzl, M. Myopathy of slaughter chickens. *Acta Univ Agric Silv* 54:49–56. 2006.
29. MacDougall, D.B. Changes in the colour and opacity of meat. *Food Chem* 9(1/2):75–88. 1982.
30. Cassens, R.G. et al. Recommendation of reference method for assessment of meat color. In *Proceedings of 41st International Congress of Meat Science and Technology*, San Antonio, TX. C86: 410–411. 1995.
31. Faustman, C. et al. Strategies for increasing oxidative stability of (fresh) meat color. In *Proceedings 49th Annual Reciprocal Meat Conference*, Provo, UT. 73–78. 1996.
32. Anderson, H.J., Bertelsen, G., and Skibsled, L.H. Colour and colour stability of hot processed frozen minced beef. Result from chemical model experiments tested under storage conditions. *Meat Sci* 28(2):87–97. 1990.
33. Fernández-Ginés, J.M. et al. Effect of storage conditions on quality characteristics of bologna sausages made with citrus fiber. *J Food Sci* 68:710–715. 2003.
34. Fernández-López, J. et al. Evaluation of antioxidant potential of hyssop (*Hyssopus officinalis* L.) and rosemary (*Rosmarinus officinalis* L.) extract in cooked pork meat. *J Food Sci* 68:660–664. 2003.
35. Pagán-Moreno, M.J. et al. The evolution of colour parameters during "chorizo" processing. Fleischwirtschaft 78(9):987–989. 1998.
36. Aleson, L. et al. Utilization of lemon albedo in dry-cured sausages. *J Food Sci* 68:1826–1830. 2003.
37. Fernández-López, J., Pérez-Alvarez, J.A., and Aranda-Catalá, V. Effect on mincing degree on color properties in pork meat. *Color Res Appl* 25:376–380. 2000a.
38. Parolari, G., Gabba, L., and Saccani, G. Extraction properties and absorption spectra of dry cured hams made with and without nitrate. *Meat Sci* 64(4):483–490. 2003.
39. Wakamatsu, J., Nishimura, T., and Hattori, A. A Zn-porphyrin complex contributes to bright red colour in Parma ham. *Meat Sci* 67(1):95–100. 2004a.
40. Ponsano, E.H.G. et al. Performance and color of broilers fed diets containing *Rhodocyclus gelatinosus* biomass. *Revista Brasileira de Ciencia Avicola* 6(4):237–242. 2004.
40. Wakamatsu, J. et al. Establishment of a model experiment system to elucidate the mechanism by which Zn-protoporphyrin IX is formed in nitrite-free dry-cured ham. *Meat Sci* 68(2):313–317. 2004b.
41. Zhou, G.H., Yang, A., and Tume, R.K. A relationship between bovine fat colour and fatty acid composition. *Meat Sci* 35(2):205–212. 1993.
42. Esteve, E. Alimentación animal y calidad de la carne. *Eurocarne* 31:71–77. 1994.
43. Verdoes, J.C. et al. Isolation and functional characterisation of a novel type of carotenoid biosynthetic gene from *Xanthophyllomyces dendrorhous*. *Mol Gen Genet* 262(3):453–461. 1999.
44. Irie, M. Optical evaluation of factors affecting appearance of bovine fat. *Meat Sci* 57:19–22. 2001.
45. Apple, J.K. et al. Influence of dietary inclusion level of manganese on pork quality during retail display. *Meat Sci* 75:640–647. 2007.
45. Zhang, X.Y. et al. Observation on inheritance of skin colour in green-shell-egg fowl. *J Yunnan Agric Univ* 17(1):39–44. 2002.
46. Woelfel, R.L. and Sams, A.R. Marination performance of pale broiler breast meat. *Poult Sci* 80(10):1519–1522. 2001.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

47. Fraqueza, M.J. et al. Incidence of pectoralis major turkey muscles with light and dark color in a Portuguese slaughterhouse. *Poult Sci* 85(11):1992–2000. 2006.
48. Fasone, V. and Priolo, A. Effect of stress on ostrich meat quality. In *Proceedings of the 3rd International Ratite Science Symposium of the World*, ed. E. Carbajo, Madrid, Spain: Poultry Science Association (WPSA). 393–396. 2005.
49. CIE. A colour appearance model for colour management systems: CIECAM02. *CIE Pub*, 159. 2004.
50. AMSA. *Guidelines for meat color evaluation*. American Meat Science Association. Chicago, IL: National Live Stock and Meat Board. 1991.
51. Hornsey, H.C. The colour of cooked cured pork. I. Estimation of the nitric oxide-haem pigments. *J Sci Food Agric* 7:534–540. 1956.
52. Agulló, E. et al. Determination of total pigments in red meats. *J Food Sci* 55:250–251. 1990.
53. Hunt, M.C. Meat color measurements. In *Proceedings of 33rd Reciprocal Meat Conference*, Chicago, IL: American Meat Science Association & National Live Stock and Meat Board. 41–46. 1980.
54. Zhu, S., Ramaswamy, H.S., and Simpson, B.K. Effect of high-pressure versus conventional thawing on color, drip loss and texture of Atlantic salmon frozen by different methods. *Lebensm Wiss u Technol* 37:291–299. 2004.
55. Sayas, M.E. Contribuciones al proceso tecnológico de elaboración del jamón curado: aspectos físicos, fisicoquímicos y ultraestructurales en los procesos de curado tradicional y rápido. [PhD Thesis]. Valencia, Spain: Universidad Politécnica de Valencia, 1997.
56. Lindahl, G., Lundström, K., and Tornberg, E. Contribution of pigment content, myoglobin forms and internal reflectance to the colour of pork loin and ham from pure breed pigs. *Meat Sci* 59(2): 141–151. 2001.
57. Brewer, M.S. et al. Measuring pork colour: effects of bloom time, muscle, pH and relationship to instrumental parameters. *Meat Sci* 57:169–176. 2001.
58. Xia, J.J. et al. Characterizing beef muscles with optical scattering and absorption coefficients in VIS-NIR region. *Meat Sci* 75:78–83. 2007.
59. Pagán-Moreno, M.J. et al. Entstehung von farbparametern während der Herstellung von "chorizo." Fleischwirtschaft 77:664–667. 1997.
60. Fox, J.B. The chemistry of meat pigments. *J Agric Food Chem* 14:20–27. 1966.
61. Millar, S.J., Moss, B.W., and Stevenson, M.H. Some observations on the absorption spectra of various myoglobin derivatives found in meat. *Meat Sci* 42(3):277–288. 1996.
62. Kanner, J. Oxidative processes in meat products: quality implications. *Meat Sci* 36:169–189. 1994.
63. Barbut, S. Effect of illumination source on the appearance of fresh meat cuts. *Meat Sci* 59:187–191. 2001.
64. Fernández-López, J. et al. Effect of sodium chloride, sodium tripolyphosphate and pH on color properties of pork meat. *Color Res Appl* 29:67–74. 2004.
65. Hildrum, K.I. et al. Near-infrared reflectance spectroscopy in the prediction of sensory properties of beef. *J Near Infrared Spectrosc* 3:81–87. 1995.
66. Feldhusen, F. Einflüsse auf die postmortale Farbveränderung der Oberfläche von Schweinemuskulatur. *Fleischwirtschaft* 74:989–991. 1994.
67. Correa, J.A. et al. Effects of slaughter weight on carcass composition and meat quality in pigs of two different growth rates. *Meat Sci* 72:91–99. 2006.
68. Windham, W.R. et al. Visible/NIR spectroscopy for characterizing fecal contamination of chicken carcasses. *Trans ASAE* 46(3):747–751. 2003a.
69. Windham, W.R. et al. Algorithm development with visible/near-infrared spectra for detection of poultry feces and ingesta. *Trans ASAE* 46(6):1733–1738. 2003b.
70. Swatland, H.J. A brief study of the effect of nitrite on bologna coloration measured with a Colormet fiber-optic spectrophotometer. *Can Inst Food Sci Technol J* 21(5):560–562. 1988.
71. Snyder, H.E. Analysis of pigments at the surface of fresh beef with reflectance spectrophotometry. *J Food Sci* 30:457–459. 1965.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

72. Fernández-López, J. et al. Characterization of the different states of myoglobin in pork meat using colour parameters and reflectance ratios. *J Muscle Foods* 11:57–68. 2000b.
73. Navarro, C. Optimización del proceso de obtención de geles cárnicos a partir de carne de ave mecánicamente recuperada. [PhD Thesis]. Universidad Miguel Hernández. Elche, Alicante, Spain. 2005.
74. Liu, Y.L. et al. Two-dimensional correlation analysis of visible/near-infrared spectral intensity variations of chicken breasts with various chilled and frozen storages. *J Agric Food Chem* 52(3): 505–510. 2004.
75. Chao, K. et al. Characterizing wholesome and unwholesome chickens by CIELUV color difference. *Appl Eng Agric* 21(4):653–659. 2005.
76. Andrés, S.I. et al. Prediction of sensory characteristics of lamb meat samples by near infrared reflectance spectroscopy. *Meat Sci* 76:509–516. 2007.
77. Berzaghi, P. et al. Near-infrared reflectance spectroscopy as a method to predict chemical composition of breast meat and discriminate between different n-3 feeding sources. *Poult Sci* 84(1):128–136. 2005.
78. Brøndum, J. et al. Prediction of water-holding capacity and composition of porcine meat by comparative spectroscopy. *Meat Sci* 55:177–185. 2000.
79. Geesink, G.H. et al. Prediction of pork quality attributes from near infrared reflectance spectra. *Meat Sci* 65:661–668. 2003.
80. Schwarze, H. Continuous fat analysis in the meat industry. In *Third European symposium on near infrared (NIR) spectroscopy*, 43–49, Report no. 996-10-1. 1996.
81. Stanford, K. et al. Video image analysis for online classification of lamb carcasses. *Anim Sci* 67:311–316. 1998.
82. Hopkins, D.L. et al. Video image analysis in the Australian meat industry—precision and accuracy of predicting lean meat yield in lamb carcasses. *Meat Sci* 67:269–274. 2004.
83. Forrest, J.C. et al. Development of technology for the early postmortem prediction of water holding capacity and drip loss in fresh pork. *Meat Sci* 55:115–122. 2000.
84. Mitsumoto, M. et al. Near-infrared spectroscopy determination of physical and chemical characteristics in beef cuts. *J Food Sci* 56:1493–1496. 1991.
85. Hildrum, K.I. et al. Prediction of sensory characteristics of beef by near-infrared spectroscopy. *Meat Sci* 38:67–80. 1994.
86. Naes, T. and Hildrum, K.I. Comparison of multivariate calibration and discriminant analysis in evaluating NIR spectroscopy for determination of meat tenderness. *Appl Spectrosc* 51:350–357. 1997.
87. Byrne, C.E. et al. Non-destructive prediction of selected quality attributes of beef by near-infrared reflectance spectroscopy between 750 and 1098 nm. *Meat Sci* 49:399–409. 1998.
88. Park, B. et al. Near-infrared reflectance analysis for predicting beef longissimus tenderness. *J Anim Sci* 76:2115–2120. 1998.
89. Cozzolino, D. et al. The use of visible and near-infrared reflectance spectroscopy to predict colour on both intact and homogenised pork muscle. *Leb Wiss Technol Food Sci* 36:195–202. 2003.
90. Cozzolino, D. and Murray, I. Effect of sample presentation and animal muscle species on the analysis of meat by near infrared reflectance spectroscopy. *J Near Infrared Spectrosc* 10:37–44. 2002.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 2

Measuring Meat Texture*

Morse B. Solomon, Janet S. Eastridge,
Ernie W. Paroczay, and Brian C. Bowker

Contents

2.1 Introduction 16
2.2 History of Meat Texture Measurements 16
2.2.1 Warner–Bratzler Shear 16
2.2.1.1 Development of the Warner–Bratzler Shear Device 16
2.2.1.2 Standard Protocol for Measuring Warner–Bratzler Shear Force 18
2.2.2 Other Texture Measurement Systems 20
2.3 Developments in Meat Texture Measurement 21
2.3.1 Digital Texture Analyzers 21
2.3.2 Test Cells, Probes, and Attachments 21
2.3.2.1 Blades 21
2.3.2.2 Needle Arrays 25
2.3.2.3 Star and Hollow Probes 26
2.3.2.4 Plumb Bob 26
2.3.2.5 Nondestructive Deformation Test 26
2.4 Innovations in Meat Texture Measurement 26
2.4.1 Isometric Tension 26
2.4.2 Spectroscopy 27
2.4.2.1 Near-Infrared Reflectance Spectroscopy 27
2.4.2.2 Raman Spectroscopy 27

* Mention of brand or firm names does not constitute an endorsement by the United States Department of Agriculture over others of a similar nature not mentioned.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

2.4.3 Sonography 28
2.4.3.1 Ultrasonics 28
2.4.3.2 Sonoelasticity 28
2.4.4 Image Analysis 28
2.4.5 Electromyography and Electrognathography 29
2.4.6 Elastography 29
2.5 Conclusions 30
References 30

2.1 Introduction

For consumers, tenderness is a critical sensory attribute of meat palatability. The perception of tenderness is influenced by many tactile senses including texture. The term "tenderness," which refers to hardness, is often used interchangeably with texture. Meat texture is a complex phenomenon that encompasses characteristics such as hardness, springiness, chewiness, cohesiveness, and even juiciness. Variations in meat texture originate from inherent differences within the structure of raw meat/muscle tissue relating to contractile protein structures, connective tissue framework, lipid, and carbohydrate components,[1,2] as well as external factors like cooking and sample handling. It has been argued that tenderness inadequately describes meat texture because it does not specify how much of the toughness sensation is due to the force to bite through meat compared with the cohesive forces that resist compression or deformation prior to rupture.[3] This chapter will not cover factors affecting texture as they are too numerous to present and discuss in this chapter and have been widely presented in many publications over the years.

The perception of texture is associated with mechanical failure properties that are related to the muscle structure.[4] Accurate and reliable measurement of texture is fundamental to the study of its variability and control.[5] Although texture is a trait that by definition can best be measured by sensory perception, researchers have continually sought to assess texture instrumentally. Instruments used for texture analysis generally measure muscle tissue's resistance to shearing, compression, and/or penetration. Although several older in-depth reviews and engineering assessments of specific meat texture devices exist,[6–8] this chapter provides an overview of the broad array of technologies developed for measuring meat texture and tenderness.

2.2 History of Meat Texture Measurements

2.2.1 Warner–Bratzler Shear

2.2.1.1 Development of the Warner–Bratzler Shear Device

The first and most widely accepted instrumental measure of meat texture over the past 80 years is the Warner–Bratzler shear (WBS) instrument. In 1928, a USDA scientist, Warner[9] presented a brief report of a mouse trap type machine equipped with a shear device that showed results strongly correlated to cooked meat tenderness and superior repeatability on raw meat measurements. In a more complete report,[10] the details of using this instrument to measure tenderness of beef were given. The instrument (Figure 2.1) consisted of a thin steel blade with a square hole in the middle slightly larger than the sample to be tested. A hand driven screw was used to pull

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

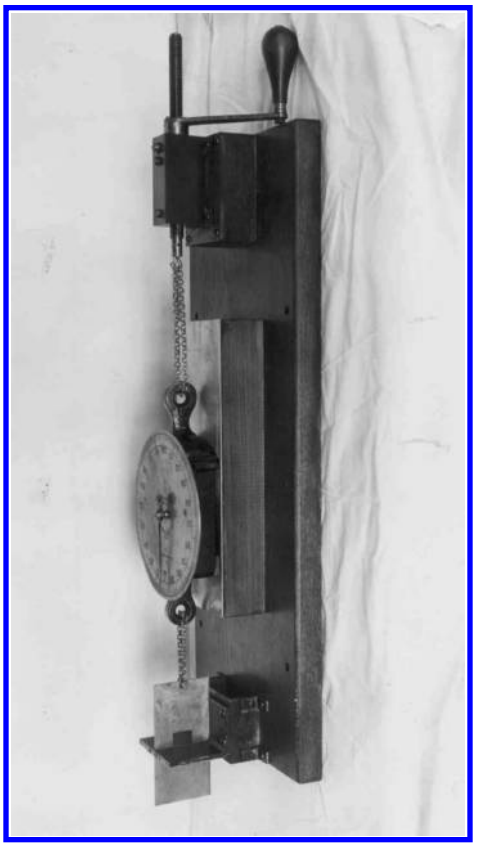


Figure 2.1 Original Warner shear device.

the blade through a narrow slit in a wooden miter box, and the maximum force required to pull the blade through the sample was recorded by a spring-type dynamometer. The specifics of the instrument configuration were refined by Bratzler, a graduate student at Kansas State University, and the instrument became known as the Warner–Bratzler shear (WBS) device[11,12] (Figure 2.2). The thickness of the steel blade was standardized at 1.016 mm, the shape of the hole in the steel blade was changed to be triangular, and the points of the triangular hole were rounded. The triangular hole was selected because, as Bratzler demonstrated using a wooden dowel, without a platform to rest the sample on this would automatically align the cylindrical core of meat perpendicular to the blade as the slot moved downward past the blade.

Operation of the WBS consisted of excising 15 mm diameter cylindrical specimens from cooked meat and placing the sample in the cutout of the blade. As the slot moves past the blade, the meat specimen is compressed and the cross-sectional shape changes to conform to the restriction imposed by the triangular opening of the blade until it is eventually sheared into two pieces. The speed for shearing the cylindrical meat cores was set at 22.86 cm/min. After determining that a machine powered by a constant speed motor was the easiest to use, Bratzler proceeded to have the G-R Electric Manufacturing Company (Manhattan, Kansas) build several copies based on his design. Some excellent discussions on the development of WBS were recounted by the inventors in early Reciprocal Meat Conferences.[13,14]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

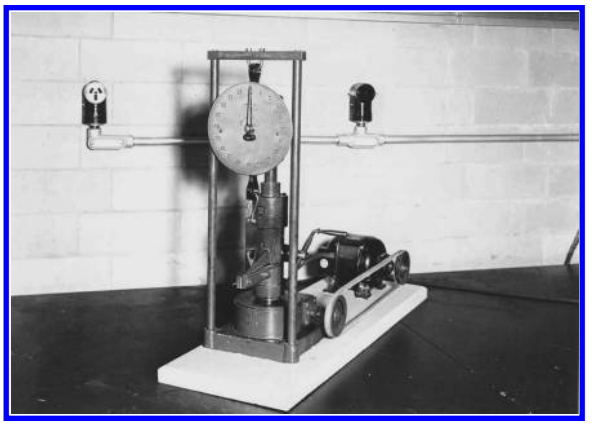


Figure 2.2 Modified Warner–Bratzler shear machine.

Studying the deformation and stresses developed in the Warner–Bratzler test and using a WBS test cell on other instruments, Voisey[8] concluded that despite the simplicity of the WBS devices, data curves are deceptively complex to interpret. The maximum force recorded during the WBS meat shear test (WBSF) is considered to be a measure of meat tenderness. Although WBS is primarily used to obtain peak force values, some researchers[15–21] have also charted the time–force curves during WBS operation to profile the forces measured. Based on the shape of these WBS time–force deformation curves, various mechanical parameters including peak force have been used to further characterize tenderness differences. The conventional interpretation, as implied in the name, is that shear forces are primarily responsible for cutting the meat specimen during WBSF measurement. Other researchers, however, argued that tensile strength[7,8,22–24] is the primary contributor in WBS shearing process and that WBS fails to account for meat's viscoelastic[25] nature.

Addressing the difficulties in standardizing WBS texture measurements, Bourne[26] concluded that frictional forces of the blade moving through the slot could be a substantial source of error and could vary considerably among instruments. The ideal texture test, according to Bourne, would be frictionless so that instruments could be calibrated in fundamental units of force, distance, or time.

Despite many years of research and innovation, the basic WBS technique or its variations remain the most widely accepted and utilized method for objectively measuring meat tenderness. In numerous studies relating WBSF to sensory panel tenderness scores, correlation coefficients have been found to range from –.92 to .7, depending on the tenderness range of the meat samples included in the study. Szczesniak[27] has an excellent discussion of correlating sensory with instrumental texture measurements. Table 2.1 lists some correlation coefficients (R) of various measures of meat texture/tenderness reported in various literature citations. Even though the WBS technique is the *de facto* standard to which other devices or techniques for measuring meat texture are compared, WBSF fails to comprehensively describe meat tenderness.

2.2.1.2 Standard Protocol for Measuring Warner–Bratzler Shear Force

The American Meat Science Association[28,29] (AMSA) first published standard protocol for determining WBS in 1978, which was updated in 1995. Since then, other scientists[30,31] have published variations

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 2.1 Correlation Coefficients (*R*) of Various Measures of Texture Reported in Literature

Comparison Factor	*Correlated To*	*Correlation Coefficient*[a]	*Reference(s)*
Sensory tenderness	WBSF	–.77 to –.92	42
	WBSF	–.63*	45
	WBSF	–.80[NR]	47
	WBSF	.68–.70**	123
	WBSF	–.63	90
	Sharp needle	–.77	75
	Sharp blade	–.52	75
	Plumb bob	–.53	75
	Plumb bob	–.71	100
	NIR raw	.42–.7	123
Sensory hardness	Needle probe	–.74	100
	Force at first yield	–.84***	66
	WBSF	.64	87
	BMORS	.54	87
Sensory toughness	BMORS cooked	.73	87
	WBSF	.8	87
	WBSF	.92***	171
WBSF raw	WBSF cooked	.82**	89, 99
WBSF, day 2 postmortem	WBSF, day 7	.66	116
	WBSF, day 14	.92	116
Resistance raw, day 2 postmortem	Resistance raw, day 8	.5	172
	Resistance raw, day 14	.8	172
BMORS raw, day 0	BMORS cooked, day 7	.56	87
NIR raw	WBSF cooked	.73–.82	123
Armour tenderometer raw	WBSF cooked	.69	89
	WBSF cooked	.48**	173, 174
	WBSF cooked	–.5	90

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 2.1 (continued) Correlation Coefficients (*R*) of Various Measures of Texture Reported in Literature

Comparison Factor	*Correlated To*	*Correlation Coefficient*[a]	*Reference(s)*
KT device	WBSF	.4**	45
Punch and die test	Instrumental	.92–.98**	50
BITE Master II	Instrumental	.86–.89[NR]	http://130.184.125.114/bite

[a] Significance of correlation: *$p < .05$, **$p < .01$, and ***$p < .001$. NR indicates not reported.

of the AMSA guidelines on the World Wide Web. Standardized protocols also have been developed and finalized for the Organisation for Economic Co-operation and Development (OECD)[32–34] and for the Cooperative Research Center[35] (CRC) in Australia. The final protocol[34] for the OECD was presented at the International Congress on Meat Science and Technology in 1997–1998.

2.2.2 Other Texture Measurement Systems

Over the years, a number of devices have been developed for objectively measuring meat texture, and many have been reviewed[6,8,23,36–42] extensively. Szczesniak and Torgeson[6] reviewed about 20 texture devices covering shearing, penetration, biting, compression, and grinding. Many texture devices never gained the popularity of WBS or were deemed not acceptable due to low correlation to WBS measurements. Among these are the Christel Texturometer,[43,44] KT device,[45] Dassow's shear-jaw device,[41] the Slice Tenderness Evaluator (STE),[46,47] NIP tenderometer,[48] a dynamometer instrument that forced food through one or more perforated plates,[49] and a punch and die[50] test cell. Some instruments such as a hand-operated forceps-type biting instrument,[51] the L&W Texturemeter,[52] and tensiometers[53] were developed for measuring raw meat; however, most have failed to adequately predict cooked meat texture.

The Volodkevich[54] bite tenderometer (VBT), introduced in 1938 and modified by Winkler[55] to have rounded or blunt wedges that pinch the sample during compression, was not further developed as an independent apparatus. However, the VBT is widely available as an attachment to modern texture analyzers. Volodkevich-style bite wedges were incorporated into the Macfarlane and Marer[56] apparatus that was modified[57] (New Zealand patent #190945) to become the MIRINZ tenderometer (AgResearch MIRINZ, Hamilton, New Zealand). The wedges do not slide past each other as would incisor teeth[58] but meet end to end. Bouton and Harris[59] confirmed that the MIRINZ tenderometer and the WBS device had very significant linear relationships ($R = .94$) signifying that both instruments were measuring the same property. The MIRINZ tenderometer is no longer manufactured.[60]

Some specialized tenderometers and texturometers were not commercialized but have been important in texture research. The MIT Denture tenderometer (Massachusetts Institute of Technology, Cambridge, Massachusetts) was meant to simulate, but not duplicate, the masticatory action of the human mouth.[61,62] The MIT tenderometer, introduced by Proctor et al.[63] and later refined by Brody,[64] was more widely accepted for dental and biomedical applications rather than for food. It became the basis of the General Foods Texturometer (General Foods Corp., White Plains, New York) that was commercialized by Zenken Co, Ltd. (Tokyo, Japan). Later, the Bi-cyclical

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Instrument for Texture Evaluation (BITE) Master artificial panelist was built at the University of Georgia, followed by the BITE Master II (University of Arkansas, Fayetteville, Arkansas; http://130.184.125.114/bitemaster/about.htm). The BITE Master II is an electrognathograph used to track the three-dimensional jaw movements during biting and records corresponding forces exerted on the food. There is limited research[65] using the BITE Master II for muscle foods.

2.3 Developments in Meat Texture Measurement

2.3.1 Digital Texture Analyzers

All modern texture measurement instruments have common components and features such as a digital stress–strain gauge, controllable crosshead speed, data acquisition, and operation in compression or tensile mode. All feature a variety of interchangeable test cells, probes, or attachments. In the United States, there are a number of manufacturers and distributors of texture analyzers (Table 2.2), and all offer test cells, jigs, or attachments equivalent to the Warner–Bratzler meat shear.

With the emergence of sophisticated data acquisition and software to analyze output, the potential number of variables for assessing texture has greatly expanded. From the time–force graphs generated with various instruments, it is possible to calculate a number of parameters, for example, total energy, work, force at first yield, slope at first yield, or other user-defined measurements. Huang et al.[66] applied step-wise regression analysis to compression test variables to calculate prediction models for tenderness and structural integrity of mutton. Among the four variables analyzed, the one most highly correlated to sensory panel evaluation of tenderness was force at first yield. When structural integrity, which they defined by a second-order mathematical model using force at first yield, was included in the model, the correlation to sensory data increased to $R^2 = .76$. Alternative texture parameters calculated from recorded data have not been utilized for elucidating the texture of meat as extensively as they have been for other food products.

2.3.2 Test Cells, Probes, and Attachments

Over the years many different test cells, probes, and attachments have been developed to fit on various instruments for the measurement of meat texture. Voisey[8] criticized equipment manufacturers because in their efforts to make attachments (test cells or jigs) interchangeable, test cells have not been standardized or verified. The various attachments described in the following sections are chiefly based on the principle of measuring the force necessary to shear, compress, or penetrate the tissue to assess meat texture. Following Bourne's[26] suggestion of using a frictionless test, tensile measurements[67] were performed as a measure of meat texture. With tensile testing, however, there were problems of attaching or gripping the meat sample. Use of a dumbbell shape[21,68] sample helped overcome gripping the sample and is the standard sample shape as outlined by Honikel.[34] Other examples of alternative tests are the texture profile analysis (TPA)[61,69] introduced by Friedman et al. and compression tests[33,34] adopted by the OECD.

2.3.2.1 Blades

2.3.2.1.1 Sharp and Blunt Blades

Bourne[7] suggested that using a flat-edge blade would simplify interpretation of time–force curves from WBS determinations. Several researchers[70–74] have investigated the possibility of using a flat-edge

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 2.2 Sources of Some Available Texture Analyzers

Manufacturer	*Texture Instrument/Features*	*Contact Information*
GR Manufacturing Company Manhattan, Kansas	Original analog Warner–Bratzler Shear Machine with a Chattilon force dial; the WBS 2000D digital model has a Chattilon strain gauge	Richard Lundquist 1317 Collins Lane Manhattan, Kansas 66502; Tel.: +1-785-537-727
Ametek TCI Division Largo, Florida and Lloyd Instruments Ltd. Hampshire, UK	Single and dual column stands in analog and digital versions that employ NEXYGEN software. Models TCM2301 and the digital TCD200 have Chattilon test stands and force gauges	www.ametek.com; www.lloyd-instruments.com
BITE Master II, University of Arkansas Fayetteville, Arkansas	A three-dimensional movement electrognathograph used to track jaw movements during biting; records corresponding forces exerted on food. This artificial panelists was the concept of Dr Jean Meullenet based on the BITE Master	http://130.184.125.114/bitemaster/about.htm
Brookfield Engineering Laboratories Middleboro, Massachusetts	Viscometers, rheology, and texture analysis equipment	www.BrookfieldEngineering.com
Food Technology Corporation Sterling, Virginia	Range of tenderometers and texture measurement systems as stand-alone or running Windows-based software	www.foodtechcorp.com
Imada, Inc. Northbrook, Illinois	Many configurations for manual and motorized test stands, mechanical and digital force gauges and data acquisition systems for compression, tension, and torsion tests	www.imada.com
Instron Corporation Canton, Massachusetts	Universal testing machines for food texture analysis capable of measuring compression and tension. The working parts of most texture-measuring devices can be used on this universal testing machine, available in single and dual column models ranging from large table top to field portable units	www.instron.com

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 2.2 (continued) Sources of Some Available Texture Analyzers

Manufacturer	*Texture Instrument/Features*	*Contact Information*
Itin Scales Company Brooklyn, New York	Supplier of grips and fixtures for food testing and force gauges; products include Chattilon test stands, grips and accessories, Imada force gauges, and Dillon Quantrol force testing equipment	www.itinscales.com
Shimadzu Scientific Instruments Columbia, Maryland	Several universal testing instruments for materials testing (single and dual beam) with analysis using Trapezium software	www.shimadzu.com
Texture Technologies, Inc. Scarsdale, New York and Stable Micro Systems Ltd. Surry, UK	TA-XTplus, TA-XT2i, and TA.XT2iHR texture analyzers with dedicated software	www.texturetechnologies.com; www.stablemicrosystems.com
Tinius Olsen Horsham, Pennsylvania	Single column food testing machines. Warner–Bratzler shear cell available with 30°, 50°, 60°, and 70° V-angles, flat, and square cutout blades	www.TiniusOlsen.com
Zenken Company, Ltd. Tokyo, Japan	This company commercialized the General Foods Texturometer[61]	
Zwick/Roell, Ltd. Kennesaw, GA and Zwick GmbH & Co. KG Ulm, Germany	Materials testing systems for texture analysis, viscosity measurement, and packaging testing; has WBS fixture with flat and V-notch blade	www.zwick.com

blade instead of the traditional V-notched Warner–Bratzler blade. Overall, it was determined that the V-shaped blade cutout resulted in lower shear values[74] compared to the flat blade for beef longissimus and semitendinosus muscles. Sharp and blunt blades and needles have been evaluated[73,75] for predicting tenderness of cooked longissimus beef using measurements on uncooked samples. Results of those studies indicated that the sharp versions of blade or needles were better than their blunt versions for predicting cooked meat tenderness and prediction results were of similar magnitude.

Shackelford et al.[70,71] presented a simplified technique for measuring longissimus muscle shear force, which they referred to as slice shear force (SSF). They developed this technique while working on a method to reduce variability in the WBS procedure and at the same time producing an online method[70] for assessment of meat tenderness. The SSF method involves cooking a 2.5 cm thick steak and then removing a 1 cm wide by 5 cm long slice parallel to the muscle fibers. The slices are then placed flat on a universal testing machine and sheared once using a blunt-end blade

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

at a crosshead speed of 500 mm/min. SSF values were reported[71] to correlate well with sensory panel tenderness values (R = –.76) and with WBSF values (R = .80).

2.3.2.1.2 Razor Blade

To obtain shear force of individual muscle fibers, Henrickson et al.[76] explored a microsensitive instrument that was fitted with a blunt-edge razor blade. Shear force and shear energy results obtained from this configuration were noted to be sensitive to differences in fiber diameter and muscle fiber type as well as to changes in chilling and deboning treatments.

A more recent variation in determining shear force is by use of a razor blade to penetrate 20 mm into cooked meat. Dubbed the Meullenet–Owen (MO) razor shear force[77–84] (RB, RBS, MOR, MORBS, or MORS), it was first used to gauge the texture of chicken breasts. MORS was reported to have high correlation to consumer sensory attributes of hardness and cohesiveness[77,79,81,85] and was correlated to the Allo-Kramer multiblade shear force of cooked broiler breasts. This novel test measures the force in Newtons (N) to penetrate an 8 mm wide × 20 mm high razor blade 20 mm into intact breast fillets[77] at crosshead speed of 60 mm/min. Improved correlation to sensory attributes was detected when a measure of shear energy (MORSE), defined as the area under the time–force curve, was used. Razor blade shear energy (MORSE = N mm) produced higher correlations (R = .84–.87) to sensory attributes than did the Allo-Kramer shear (R = .68–.71).

The effect of blade penetration depth, investigated using MORS,[79] revealed that a penetration depth of at least 10 mm was required to obtain consistent correlations (.82–.85) to expert and consumer panel sensory evaluations. As penetration depth increased to 20 mm, the correlation with the trained sensory panel hardness and cohesiveness scores increased, whereas consumer panel acceptance of texture and tenderness decreased. Xiong et al.[79] also showed strong correlation of MORSE values at various penetration depths when they were converted by a multiplication factor to standardize MORSE values equal to a 20 mm penetration depth.

Prediction of broiler breast tenderness by MORS was evaluated[85] using two instruments, a common texture measurement system and a portable texture analyzer. MORS and MORSE values from both instruments were correlated. For both texture analyzers evaluated, the shear energy MORSE values were more highly correlated to sensory and with a lower error rate than to peak shear MORS values. This indicates potential for online application by using a portable texture analyzer for predicting breast tenderness.

Changes in breast fillets occurring during long-term freezing for up to 8 months were detected[86] using MORSE values. A razor blade (8.9 mm wide × 0.5 mm thick × 30 mm high) was used to shear muscle fibers to a depth of 20 mm perpendicular to the fiber orientation. Crosshead speed was not given. Tenderness MORSE values were modeled[85] using a modified Goempertz equation to fit a sigmoid shape response that enabled establishing tenderness classifications based on MORSE values that correlated to sensory tenderness values.

Alpers, Priesmeyer, and Meullenet evaluated a blunt MO razor blade[87] (BMORS) for its effectiveness in predicting tenderness of beef using raw or cooked samples. Although not statistically different, the correlation of sensory hardness ratings to shear force was higher for WBS (R^2 = .64) than for BMORS (R^2 = .54) values for cooked meat. The relationship between BMORS shear values on raw meat to sensory ratings after 7 day aging was not as strong (R^2 = .31) as in cooked meat. It was demonstrated in this experiment that no-roll beef carcasses could be segregated into tenderness classifications within 48 h based on in-plant BMORS[87] values of the exposed ribeye muscle.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

2.3.2.2 Needle Arrays

Researchers have also attempted to measure meat texture using needle or probe devices. The general idea is that the degree of penetration or compression and the associated force required relate to meat tenderness. These tests vary widely in the number of needles or probes, the dimensions, arrangement, and sharpness/bluntness of the individual needles or probes.

To measure tenderness in chicken breast samples, Peterson and Lilyblade[44] utilized a modified version of an earlier device, the Christel Texturometer,[43] attached to a Lee–Kramer apparatus. The modified attachment consisted of a circular pattern of 25 solid steel cylinder rods that were forced simultaneously through chicken breast sample in a modified Kramer shear attachment. A few years later, Hansen[88] developed the Armour Meat Tenderometer that recorded force to press 10 sharp tip 3.18 mm diameter needles into raw meat. In the design and testing, Hansen used the needle array attached to a universal testing (Instron) apparatus and demonstrated high correlation (.69) to sensory evaluation of tenderness and to WBS (.82). The final design of the portable instrument[89] for use in the packing plant measured the maximum force to press a 10-needle probe 5 cm into the ribeye (at the 12th rib location) of the beef carcass. Research using the Armour tenderometer yielded conflicting results[48,90–95] of efficacy because the force detector was highly dependent on operator technique,[8] and further use was abandoned.

Another needle penetrometer[96] was developed by the U.S. Army Food Engineering Laboratory, Natick, Massachusetts. The lack of additional reference to this penetrometer indicates it likewise, was not widely adopted for use. Morrow and Mohsenin[97] evaluated the mechanics of a multiple needle tenderometer for raw meat and concluded it would be possible to use a conical indenter to measure yield pressure independent of probe geometry and penetration depth.

A MIRINZ tenderness probe[98] consisting of two concentric sets of pins, one set static and one rotating, was evaluated in a series of experiments to predict beef tenderness based on measurements on raw samples. The design was considered nondestructive since researchers could obtain an objective estimate of cooked meat tenderness without introducing additional variation due to obtaining core samples needed to perform WBS. The amount of torque measured at 50° of rotation was most highly related to both trained panel and consumer sensory characteristics. On continued testing using both tension and shear heads on raw and cooked strip loin steaks, results confirmed that the probe values were measuring essentially the same characteristics. However, it was determined that the probe values from raw samples did not account for a sufficient amount of variation in either sensory or consumer judged traits to be useful. This MIRINZ tenderness probe outperformed WBS for predicting consumer sensory traits.

A recently evaluated[99,100] multineedle probe having two rows of three needles, 0.32 cm diameter with 10° tapered point, similar to those of the Armour tenderometer, was used to predict tenderness of strip loin steaks using mechanical measurements made on raw beef. The correlations[100] presented were of the same magnitude as those reported by Hansen[88,89] when the Armour tenderometer was used on a universal testing apparatus.

Some research on texture measurement devices has suggested that the shape and sharpness of the meat contact point is important. Hinnergardt and Tuomy[101] evaluated needle or probe ends including flat, pointed, dull, and tapered flat (blunt) to evaluate pork chops. They determined the optimal configuration would be an array of five flat-end (semiblunt) needles (3.175 mm diameter tapered to 0.18 cm diameter at the end) penetrating 1.27 cm into the meat. Using various mechanical probes[73,75] to predict tenderness of cooked beef longissimus based on measurements of uncooked samples that compared to sharp to blunt devices, sharp needles and sharp blades were

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

more successful in predicting sensory panel scores with an overall ability to explain 47–50% of the variability.

2.3.2.3 Star and Hollow Probes

A star probe[102] (round punch with six tapered points) was employed for evaluating texture of pork loins, and was noted to have good correlation to sensory evaluation. The star probe is a cylindrical punch (solid or tubular) with four, five, or six tapered points and, most likely, is an adaptation of a cherry, date, or olive pitter. Huff-Lonergan et al.[102] described the probe as a five-pointed cherry pitter, 9 mm diameter and with 6 mm between each point. It was employed to determine the amount of force needed to punch and compress a pork chop to 80% of the sample height. The investigators noted highly significant correlation ($R = -.54$) to sensory tenderness scores. A star probe was also mentioned by researchers[103] at Lacombe in Canada; however, similar to the former report,[102] no additional information was presented on the background or why this probe was selected.

A novel probe called the "tensipresser"[104] consists of a round, 5.5 mm diameter hollow cylinder pressed repeatedly into meat to mimic chewing through a 1.0 cm thick pork sample. The first compression cycle is 0.5 mm deep and each successive chew cycle increases the depth by 0.04 mm. By increasing the compression depth in this manner, it takes 250 cycles to bite through the sample. Values representing peak stress at maximum penetration, severing threshold value, and a pliability measure were calculated from the tensipressor data.

2.3.2.4 Plumb Bob

The use of a plumb bob among other probes was mentioned in investigations of mechanical probes to predict tenderness of meat.[73,99] It is not clear whether the plumb bob was meant to represent a "conical indenter" mentioned by Morrow and Mohsenin[97] in their assessment of needle designs; although, the plumb bob would apply both tensile and compression forces as it penetrates muscle. The peak penetration force as the plumb bob (9.6 cm long, 20° taper, diameter maximum of 3.5 cm to 0 cm at the point) was pressed 6.9 cm into meat, perpendicular to the meat surface, at crosshead speed of 250 mm/min was measured on raw and cooked samples. Plumb bob prediction equations for tenderness were comparable to those derived using WBS.

2.3.2.5 Nondestructive Deformation Test

Nondestructive deformation tests[80] of raw broiler breast meat were performed using cylindrical probes 2, 5, 6, or 8 mm diameter for classifying breasts as tender or tough. A significant correlation coefficient, approximately $R = .6$, between the deformation test and razor blade shear energy was detected only when using the 8 mm probe. Tests demonstrated that 81% of all breast samples could be correctly classified as tender or tough in online testing and warrant further evaluation.

2.4 Innovations in Meat Texture Measurement

2.4.1 Isometric Tension

Isometric tension development during onset of rigor was measured in bovine,[105,106] porcine[107] and rabbit muscle,[53] poultry,[108] and salmon.[109] The RigoTech Muscle Texture Analyzer® (Rheologica

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Instruments, Inc., Lund, Sweden) was offered by ATS RheoSystems (Bordentown, New Jersey) as an analytical instrument for measuring muscle shortening and isometric tension in relation to rigor development and meat tenderness. Its primary use was for determining optimal cooling conditions to optimize meat tenderness. The consensus of two primary studies[53,108] employing isometric tension development was that postmortem isometric tension changes are probably not directly related to cooked meat texture due to relatively large differences in tension pattern that are required to cause small changes in tenderness.

2.4.2 Spectroscopy

Fluorescence[110–114] and other optical spectra probes have been evaluated for usefulness to segregate meat into tenderness classifications with varying degrees of success. An attempt to assess pork tenderness using WBS and online methods that included pH, light scattering, conductivity, and double density light transmission[115] was considered not successful. Egelandsdal et al.[116] attempted to determine tenderness of beef longissimus muscles at 2 days postmortem using fluorescence emission spectra; however, they concluded that wide variation in chilling rates between muscles and carcasses combined with variations in equipment wavelengths used and light sources restricted the application of this autofluorescence methodology.

2.4.2.1 Near-Infrared Reflectance Spectroscopy

Near-infrared reflectance (NIR) spectroscopy has been the subject of research[117–120] to evaluate its potential for predicting meat tenderness based on near-line or online measurements in raw meat. For many years, NIR spectrography was utilized for assessing chemical composition of foods; however, in recent years the technology has been investigated for meat texture measurements[121] with varying success. Correlation values (R^2) to predict shear force measurements in beef[118–120,122,123] ranged from .22 to .83 and are influenced by wavelength, environment, and instrumental variations such as lamp source. Initial NIR work sought to predict tenderness[118,119] measured by WBS. Later, NIR was related to SSF at 14 days postmortem and resulted in development of the QualitySpec® BT equipment (Analytical Spectral Devices, Inc., Boulder, Colorado) now in commercial production to perform online sorting of tough and tender beef.

NIR spectra were also compared to razor blade shear (MORS) and shear energy (MORSE)[117] for assessing and sorting poultry breasts for toughness. Calibration and validation R^2 values ranged from .9 to .95 and .84 to .89, respectively; although, regressions did not yield satisfactory model statistics. The investigators[117] suggested that more samples with greater range of tenderness would be needed to develop better predictions to make NIR a viable technology for estimating tenderness.

2.4.2.2 Raman Spectroscopy

Beattie et al.[124] confirmed the potential for using Raman spectroscopy for predicting sensory quality of beef. Light scattered from a molecule typically is elastic, that is, of the same energy (frequency) and wavelength as the incident light. In Raman spectroscopy, however, light is scattered with a shift in optical frequency. Raman spectroscopy is based on light scattering of monochromatic light, usually from a laser in the near-infrared range, and yields similar information to NIR spectroscopy.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

2.4.3 Sonography

2.4.3.1 Ultrasonics

Ultrasonic properties such as velocity, attenuation, and backscatter intensity have been used to assess physicochemical properties of many foods. Sonography has been investigated for monitoring food cooling and freezing,[125–127] composition,[128–130] and has potential for predicting food texture.[129,131–135] Ultrasonic technology applied by Park and Chen[136] determined that shear wave velocity decreased at a rate of 2.97 m/s for every unit percentage increase in fat concentration in beef longissimus muscle. Based on the ability to quantify ultrasonic shear velocity, these researchers envisioned ultrasonic techniques could be used to evaluate tenderness of meat; although, earlier attempts to correlate ultrasonic spectral analysis[137] indicated accuracy of prediction models was not adequate. Connective tissue amount and shear force measurement correlated more with ultrasonic parameters at low frequency, however, and could be useful as a noninvasive tool to measure meat texture.[137]

2.4.3.2 Sonoelasticity

Nondestructive methods that may be useful for determining meat texture include sound wave velocity measurements made by ultrasonics,[136–139] sonoelasticity,[140] and nondestructive deformation tests.[80] Abouelkaram et al.[138] analyzed beef muscle textural characteristics using ultrasonic methods. Ultrasonic acoustic velocity, attenuation, and backscattering intensity revealed components of muscle structure that would influence texture. The changes in meat during rigor onset and aging were tracked by Ayadi et al.[140] using sonoelasticity. In sonoelasticity, low-frequency vibrations are applied to muscle and wave propagation characteristics are detected by simultaneously transmitted ultrasonic waves. Stress at constant 20% of strain was greatest at onset of rigor and correlated to muscle pH measurements. The velocity curve had the same qualitative changes as stress, whereas attenuation had an inverse shape. During the aging period, stress values decreased by a factor of eight to nine times representing a decrease in mechanical resistance of the meat. This decrease in mechanical resistance was accompanied by a decrease in the velocity of the mechanical wave and, inversely, an increase in attenuation. Ayadi et al.[140] interpreted this to indicate changes in mechanical resistance and wave velocity could be used as a nondestructive test to follow rigor development and aging. More research to refine the methodology and correlate findings to sensory textural evaluations are needed for this technology.

2.4.4 Image Analysis

Computer-assisted image capture, processing, and image analysis can reveal texture variations that can be related to sensory[141–147] and quality traits.[148–150] Color features have long been useful for quality classification of intact pork due to the relationship of color and pH for identifying pale, soft, and exudative pork[144] and for predicting beef texture.[151] Sorting beef carcasses using the Beef Cam[152,153] relies on grading (marbling) and color assessments, whereas other systems[142,143,154–158] identify morphological features such as the amount and thickness of connective tissue, marbling amount and distribution, and prominence of meat grain. Correlations between observed and predicted tenderness scores, however, indicated that image analysis has only marginal accuracy for predicting tenderness precisely. Use of wavelet, Gabor, and neural network modeling[147,159] has

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

improved predictive value of image analysis to assess tenderness. Continued advances in image analysis may prove useful for assessing meat texture in the future.

Dual energy x-ray absorptiometry (DEXA) imaging showed some promise as a noninvasive measurement of meat tenderness properties.[160] For measurements on whole steaks, DEXA-predicted shear force was correlated (R^2 = .69) to mean peak force measured using a MIRINZ tenderometer. Small sample size and sample handling limited fully investigating this technique; although, the results are encouraging to continue further research into this novel technique for measuring meat texture.

A nondestructive shape profiling system[78] consisting of conveyor belt, laser displacement sensors, and portable computer was used to measure shape profiles of deboned breast fillets online. The shape profiles were related to shear energy (MORSE). Shear energy increased as breast thickness increased and decreased when breast length and width increased. Using shape analysis, 83% of breast samples could be correctly classified as tender or tough when assessed online.

2.4.5 Electromyography and Electrognathography

Electromyography (EMG) and electrognathography (EGN) are considered noninvasive techniques that make it possible to study the dynamics of mastication[65,161] as it relates to meat texture. For these evaluations, a sensory panelist has electrodes placed over facial muscles and the mandibular joint to measure muscle activity and forces during chewing. In the case of EGN, a magnet is also positioned on the lower incisor teeth for tracking jaw movements. These devices have revealed differences in individuals in number of chews, speed of chewing, and first bite force generated among other parameters. Lee et al.[65] noted that all subjects perceived texture of breast meat differently even though they were highly trained in descriptive attribute testing of meat. The EGN results showed that subjects' chewing behavior generally was not affected by meat tenderness and few correlations to tenderness were detected. EMG results for meat tenderness showed variation in 13 of 19 parameters measured; however, elucidation of how parameters sensed on the first bite relate to later chews is still needed.

2.4.6 Elastography

Elastography is quantitative imaging of strain and elastic modulus distributions in soft tissues[162–164] by measuring the internal displacement of small tissue elements in response to externally applied stress using ultrasonic pulses. The method is based on external tissue compression with subsequent computation of the strain profile along the transducer axis using standard ultrasound equipment. In conventional elastography, axial strain elastograms are generated by cross-correlating pre- and post-compression digitized radio frequency echo frames acquired from the tissue before and after small uniaxial compression, respectively.[165] The resulting two-dimensional elastogram shows softer, more elastic tissue as light-colored regions. Applied to meat science, this method[145] has potential to detect differences in elasticity of muscle bundles, connective tissue amounts, and quantity of intramuscular fat. Correlation of elastographic data to meat texture lags behind its application in the medical field where it is used extensively in cardiology and other fields such as physical therapy. Huang et al.[66,166] introduced ultrasonic elastography wavelet texture features[166,167] to predict meat quality. They reported high correlation of wavelet features to meat texture variables indicating potential for developing this technology for application in meat technology. Berg et al.[164] used elastography to calculate textural hardness and intramuscular fat in pork semimembranosus muscle. They determined that

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

elastographic measurements were significantly correlated to shear force, but concluded that more research was necessary before being applied as a screening tool to identify tender meat.

A more recent development in elastography is magnetic resonance elastography (MRE),[168] which is capable of measuring *in vivo* elasticity and viscosity of living skeletal muscle tissue. In MRE, shear waves are induced into muscles using pneumatic and mechanical drivers. A magnetic resonance–compatible load cell records the force during contraction that is related to stiffness. The wavelength is sensitive to the morphology (unipennate or longitudinal) and fiber composition (type I or II) of muscles.[169] The viscoelastic property of muscle is detected by varying the vibration frequency applied to the muscles.

2.5 Conclusions

Owing to the complex and highly structured nature of muscle tissue, meat has inherently variable texture. Unfortunately, the multifaceted characteristic of meat texture has made it difficult to assess instrumentally. Some have argued that the absence of consistent terminology and lack of standardization of the test apparatus has hindered the interpretation of data and understanding of meat texture.[8] To better predict and control meat tenderness issues, accurate measures of meat texture are needed. Consequently, many technologies that measure the physical properties of meat as a measure of meat texture have been developed with varying degrees of success.

In the United States, there are at least 11 manufacturers or distributors of texture analyzers, and all offer test cells for the WBS test. Regardless of manufacturer, these texture measurement systems are remarkably similar in design: crosshead speed control, similar digital stress–strain gauges, interchangeable test cell attachments, advanced data acquisition, and software to manage and calculate data. The increased number of manufacturers for texture analysis benefits the researcher with competitive prices and choices for research. Although much has been learned over the years, instrumentally measuring and understanding characteristics of meat that correlate highly with the complex, sensory phenomenon of meat texture has proven difficult. The difficulty in predicting meat tenderness using instrumental measures also stems from the lack of understanding of the consumers' perception of texture and tenderness. It is a misconception that we can rely on a single WBS force value to adequately describe the complex nature of meat texture. Progress in measuring biomechanical characteristics[170] of raw meat and establishing correlation to overall sensory scores continues to improve, and there are some promising technologies that may allow noninvasive or nondestructive testing to achieve this goal.

References

1. Bailey, A.J. The basis of meat texture. *J. Sci. Food Agric.* 23, 995, 1972.
2. Dransfield, E., Béchet, D., and Ouali, A. Origins of variability in meat texture: an introduction to the workshop "Proteolysis and meat quality". *Sci. Alim.* 14, 369, 1994.
3. Hamann, D.D., Calkins, C.R., and Hollingsworth, C.A. Instrumental texture measurements for processed meat products. In *Proceedings of the 40th Annual Reciprocal Meat Conference*, National Live Stock and Meat Board, Chicago, IL, 1987, 19.
4. Dransfield, E. Intramuscular composition and texture of beef muscles. *J. Sci. Food Agric.* 28, 833, 1977.
5. Dransfield, E. and MacFie, H.J.H. Precision in the measurement of meat texture. *J. Sci. Food Agric.* 31, 62, 1980.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

6. Szczesniak, A.S. and Torgeson, K.W. Methods of meat texture measurement viewed from the background of factors affecting tenderness. *Adv. Food Res.* 14, 33, 1965.
7. Bourne, M.C. Interpretation of force curves from instrumental texture measurements. In DeMan, J.M., Voisey, P.W., Rasper, V.F., and Stanley, D.W. (Eds.) *Rheology and Texture in Food Quality*. AVI Publishing Co., Inc., Westport, CT, 1976, 244.
8. Voisey, P.W. Engineering assessment and the critique of instruments used for meat tenderness evaluation. *J. Text. Stud.* 7, 11, 1976.
9. Warner, K.F. Progress report of the mechanical test for tenderness of meat. *Proc. Am. Soc. Anim. Prod.* 21, 114, 1928.
10. Black, W.H., Warner, K.F., and Wilson, C.V. *Beef Production and Quality as Affected by Grade of Steer and Feeding Grain Supplement on Grass*. USDA, Washington, DC, 1931, Vol. 217, 1.
11. Bratzler, L.J. *Measuring the Tenderness of Meat by Mechanical Shear*. MSc thesis, Kansas State College, Manhattan, KS, 1932.
12. Bratzler, L.J. *Physical Research in Meat (Final Report)*. USDA and Kansas State Experiment Station, Manhattan, KS, 1933.
13. Bratzler, L.J. Determining the tenderness of meat by use of the Warner–Bratzler method. In *Proceedings of the 2nd Annual Reciprocal Meat Conference*, National Live Stock and Meat Board, Chicago, IL, 1949, 117.
14. Warner, K.F. Adventures in testing meat for tenderness. In *Proceedings of the 5th Annual Reciprocal Meat Conference*, National Live Stock and Meat Board, Chicago, IL, 1952, 156.
15. Purslow, P.P. The fracture properties of cooked beef muscle. In *30th International Congress of Meat Science and Technology*, Bristol, UK, 1984, 172.
16. Purslow, P.P., Donnelly, S.M., and Savage, A.W.J. Variations in the tensile adhesive strength of meat-myosin junctions due to test configurations. *Meat Sci.* 19, 227, 1987.
17. Purslow, P.P. Measuring meat texture and understanding its structural basis. In Vincent, J.F.V. and Lillford, P.J. (Eds.), *Feeding and the Texture of Food*. Cambridge University Press, New York, NY, 1991, 35.
18. Moller, A.J. Analysis of Warner–Bratzler shear pattern with regard to myofibrillar and connective tissue components of tenderness. *Meat Sci.* 5, 247, 1981.
19. King, N.L. and Jones, P.N. Analysing Warner–Bratzler curves. *J. Text. Stud.* 14, 283, 1983.
20. Voisey, P.W. Interpretation of force–deformation curves from the shear-compression cell. *J. Text. Stud.* 8, 19, 1977.
21. Bouton, P.E., Harris, P.V., and Shorthose, W.R. Possible relationships between shear, tensile, and adhesion properties of meat and meat structure. *J. Text. Stud.* 6, 297, 1975.
22. Pool, M.F. and Klose, A.A. The relation of force to sample dimensions in objective measurement of tenderness of poultry meat. *J. Food Sci.* 34, 524, 1969.
23. Voisey, P.W. and Larmond, E. Examination of factors affecting performance of the Warner–Bratzler meat shear test. *J. Inst. Can. Sci. Technol. Alim.* 74, 243, 1974.
24. Kapsalis, J.G. and Szczesniak, A.S. Instrumental testing of meat texture—comments on the past, present and future. *J. Text. Stud.* 7, 109, 1976.
25. Spadaro, V., Allen, D.H., Keeton, J.T., Moreira, R., and Boleman, R.M. Biomechanical properties of meat and their correlation to tenderness. *J. Text. Stud.* 33, 59, 2002.
26. Bourne, M.C. Standardization of texture measuring instruments. *J. Text. Stud.* 3, 379, 1972.
27. Szczesniak, A.S. Correlating sensory with instrumental texture measurements—an overview of recent developments. *J. Text. Stud.* 18, 1, 1986.
28. AMSA. *Research Guidelines for Cookery, Sensory Evaluation and Instrumental Tenderness Measurements of Fresh Meat.* American Meat Science Association and National Live Stock and Meat Board, Chicago, IL, 1995.
29. AMSA. *Guidelines for Cookery and Sensory Evaluation of Meat.* American Meat Science Association and National Live Stock and Meat Board, Chicago, IL, 1978.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

30. Savell, J., Miller, R., Wheeler, T., Koohmaraie, M., Shackelford, S., Morgan, B., Calkins, C., Miller, M., Dikeman, M., McKeith, F., Dolezal, G., Henning, B., Busboom, J., West, R., Parrish, F., and Williams, S. http://savell-j.tamu.edu/shearstand.html, Accessed on January 8, 2000.
31. Wheeler, T.L., Koohmaraie, M., Shackelford, S.D. http://192.133.74.2...w.protocol/wbs.html, Accessed on 8/1/2000.
32. Chrystall, B.B., Culioli, J., Demeyer, D., Honikel, K.O., Moller, A.J., Purslow, P., Schwagele, F., Shorthose, R., and Uytterhaegen, L. Recommendation of reference methods for assessment of meat tenderness. In *40th International Congress of Meat Science and Technology*, The Hague, The Netherlands, 1994, 1, S-V.06.
33. Honikel, K.O. Reference methods supported by OECD and their use in Mediterranean meat products. *Food Chem.* 59, 573, 1997.
34. Honikel, K.O. Reference methods for the assessment of physical characteristics of meat. *Meat Sci.* 49, 447, 1998.
35. Boccard, R., Buchter, L., Casteels, E., Cosentino, E., Dransfield, E., Hood, D.E., Joseph, R.L., MacDougall, D.B., Rhodes, D.N., Schon, I., Tinbergen, B.J., and Touraille, C. Procedures for measuring meat quality characteristics in beef production experiments. Report of a working group in the Commission of the European Communities (CEC) beef production research programme. *Livest. Prod. Sci.* 8, 385, 1981.
36. Bourne, M.C., Moyer, J.C., and Hand, D.B. Measurement of food texture by a universal testing machine. *Food Technol.* 20, 522, 1966.
37. Voisey, P.W. Modernization of texture instrumentation. *J. Text. Stud.* 2, 129, 1971.
38. Voisey, P.W. and Kloek, M. Effect of cell size on the performance of the shear-compression texture test cell. *J. Text. Stud.* 12, 133, 1981.
39. Voisey, P.W. and Hansen, H. A shear apparatus for meat tenderness evaluation. *Food Technol.* 21, 37A, 1967.
40. Szczesniak, A.S. Correlating sensory with instrumental texture measurements—an overview of recent developments. *J. Text. Stud.* 18, 1, 1987.
41. Szczesniak, A.S. Instrumental methods of texture measurements. In Kramer, A. and Szczesniak, A.S. (Eds.), *Texture Measurements of Foods: Psychophysical Fundamentals; Sensory, Mechanical, and Chemical Procedures and Their Interrelationships.* D. Reidel Publishing, Co., Boston, MA, 1973, 71.
42. Pearson, A.M. Objective and subjective measurements for meat tenderness. In *Proceedings of the Meat Tenderness Symposium*, Campbell Soup Co., Camden, NJ, 1963.
43. Miyada, D.S. and Tappel, A.L. Meat tenderization. I. Two mechanical devices for measuring texture. *Food Technol.* 10, 142, 1956.
44. Peterson, D.W. and Lilyblade, A.L. Relative differences in tenderness of breast muscle of normal and two dystrophic mutant strains of chickens. *J. Food Sci.* 34, 142, 1969.
45. Kelly, R.F., Taylor, J.C., and Graham, P.P. Preliminary comparisons of a new tenderness measuring device with objective and subjective evaluations of beef. *J. Anim. Sci.* 19, 645, 1960.
46. Alsmeyer, R.H., Kulwich, R., and Hiner, R.L. Loin-eye tenderness variations measured by the STE. *J. Anim. Sci.* 21, 977, 1962.
47. Kulwich, R., Decker, R.W., and Alsmeyer, R.H. Use of a slice-tenderness evaluation device with pork. *Food Technol.* 17, 83, 1963.
48. Smith, G.C. and Carpenter, Z.L. Mechanical measurements of meat tenderness using the NIP tenderometer. *J. Text. Stud.* 4, 196, 1973.
49. Voisey, P.W., Kamel, B.S., Evans, G., and DeMan, J.M. A dynamometer instrument for measurement of textural characteristics of foods. *Can. Inst. Food Sci. Technol. J.* 7, 250, 1974.
50. Segars, R.A., Hamel, R.G., Kapsalis, J.G., and Kluter, R.A. A punch and die test cell for determining the textural qualities of meat. *J. Text. Stud.* 6, 211, 1975.
51. Purchas, R.W. Some aspects of raw meat tenderness. A study of some factors affecting its change with cooking and a new means of measurement. *J. Food Sci.* 38, 556, 1973.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

52. Locker, R.H. and Wild, D.J.C. A machine for measuring yield point in raw meat. *J. Text. Stud.* 13, 71, 1982.
53. Busch, W.A., Goll, D.E., and Parrish Jr., F.C. Molecular properties of postmortem muscle. Isometric tension development and decline in bovine, porcine and rabbit muscle. *J. Food Sci.* 37, 289, 1972.
54. Volodkevich, N.N. Apparatus for measurements of chewing resistance or tenderness of foodstuffs. *J. Food Sci.* 3, 221, 1938.
55. Winkler, C.A. Tenderness of meat: I. A recording apparatus for its estimation, and relation between pH and tenderness. *Can. J. Res.* 17, 8, 1939.
56. Macfarlane, P.G. and Marer, J.M. An apparatus for determining the tenderness of meat. *Food Technol.* 20, 838, 1966.
57. Macfarlane, P.G. and Frazerhurst, L.F. Device for measuring tenderness of meat. New Zealand Patent #190945, 1980.
58. Phillips, D.M. A new technique for measuring texture and tenderness. In Valin, C. (Ed.), *38th International Congress of Meat Science and Technology*. Elsevier Applied Science, Barking, UK, 1992, 958.
59. Bouton, P.E. and Harris, P.V. The effects of cooking temperature and time on some mechanical properties of meat. *J. Food Sci.* 37, 140, 1972.
60. Rosenvold, K. Personal communication, July 10, 2007.
61. Friedman, H.H., Whitney, J.E., and Szczesniak, A.S. The texturometer—a new instrument for objective texture measurement. *J. Food Sci.* 28, 390, 1963.
62. Szczesniak, A.S. and Hall, B.J. Application of the General Foods Texturometer to specific food products. *J. Text. Stud.* 6, 117, 1975.
63. Proctor, B.E., Davison, S., Malecki, G.J., and Welch, M. A recording strain-gauge denture tenderometer for foods. I. Instrument evaluation and initial tests. *Food Technol.* 9, 471, 1955.
64. Brody, A.L. Masticatory properties of foods by the strain gage denture tenderometer. PhD dissertation, Massachusetts Institute of Technology, Boston, MA, 1957.
65. Lee, Y.-S., Saha, A., Owens, C.M., and Meullenet, J.-F. Prediction of tenderness of broiler breast fillets by electromyography (EMG) and electrognathography (EGN). In *IFT Annual Meeting Book of Abstracts*, IFT Press, Chicago, IL, 2007, 280.
66. Huang, F., Dethmers, A.E., and Robertson, J.W. A rheological method for evaluating the textural qualities of cooked mutton. *J. Food Sci.* 42, 721, 1977.
67. Stanley, D.W., McKnight, L.M., Hines, W.G.S., Usborne, W.R., and DeMan, J.M. Predicting meat tenderness from muscle tensile properties. *J. Text. Stud.* 3, 51, 1972.
68. Bouton, P.E. and Harris, P.V. A comparison of some objective methods used to assess meat tenderness. *J. Food Sci.* 37, 218, 1972.
69. Szczesniak, A.S., Brandt, M.A., and Friedman, H.H. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. *J. Food Sci.* 28, 397, 1963.
70. Shackelford, S.D., Wheeler, T.L., and Koohmaraie, M. Tenderness classification of beef: II. Design and analysis of a system to measure beef longissimus shear force under commercial processing conditions. *J. Anim. Sci.* 77, 1474, 1999.
71. Shackelford, S.D., Wheeler, T.L., and Koohmaraie, M. Evaluation of slice shear force as an objective method of assessing beef longissimus tenderness. *J. Anim. Sci.* 77, 2693, 1999.
72. Shackelford, S.D., Wheeler, T.L., and Koohmaraie, M. Technical note: Use of belt grill cookery and slice shear force for assessment of pork longissimus tenderness. *J. Anim. Sci.* 82, 238, 2004.
73. Stephens, J.W., Unruh, J.A., Dikeman, M.E., Hunt, M.C., Lawrence, T.E., and Loughin, T.M. Mechanical probes can predict tenderness of cooked beef longissimus using uncooked measurements. *J. Anim. Sci.* 82, 2077, 2004.
74. Otremba, M.M., Dikeman, M.E., Milliken, G.A., Stroda, S.L., Unruh, J.A., and Chambers, E. Interrelationships among evaluations of beef longissimus and semitendinosus muscle tenderness by Warner–Bratzler shear force, a descriptive-texture profile sensory panel, and a descriptive attribute sensory panel. *J. Anim. Sci.* 77, 865, 1999.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

75. Stephens, J.W., Unruh, J.A., Dikeman, M.C., Hunt, M.C., Lawrence, T.E., and Loughin, T.M. Mechanical probes used on uncooked strip loins can predict cooked longissimus beef tenderness. In *Proceedings of the 56th Annual Reciprocal Meat Conference*, American Meat Science Association and National Cattlemen's Beef Association, Savoy, IL, 2003, 124.
76. Henrickson, R.L., Marsden, J.L., and Morrison, R.D. An evaluation of a method for measuring shear force for an individual muscle fiber. *J. Food Sci.* 39, 15, 1974.
77. Cavitt, L.C., Owens, C.M., Meullenet, J.F., Gandhapuneni, R.K., and Youm, G.Y. Rigor development and meat quality of large and small broilers and the use of Allo-Kramer shear, needle puncture, and razor blade shear to measure texture. *Poult. Sci.* 80(Suppl. 1), 138, 2001.
78. Meullenet, J.-F.C., Xiong, R., Saha, A., and Owens, C. Novel shape profiling method for classifying tender and tough broiler breast meat. In *IFT Annual Meeting Book of Abstracts*. IFT Press, Chicago, IL, 2005.
79. Xiong, R., Meullenet, J.-F.C., Cavitt, L.C., and Owens, C. Effect of razor blade penetration depth on correlation of razor blade shear values and sensory texture of broiler major pectoralis muscles. In *IFT Annual Meeting Book of Abstracts*. IFT Press, Chicago, IL, 2005.
80. Xiong, R., Meullenet, J.-F.C., and Owens, C. Classification of tender and tough broiler breast meat by a non-destructive deformation test. In *IFT Annual Meeting Book of Abstracts*. IFT Press, Chicago, IL, 2005.
81. Cavitt, L.C., Youm, G.W., Meullenet, J.F., Owens, C.M., and Xiong, R. Prediction of poultry meat tenderness using razor blade shear, Allo-Kramer shear, and sarcomere length. *J. Food Sci.* 69, SNQ11, 2004.
82. Cavitt, L.C., Meullenet, J.F., Gandhapuneni, R.K., Youm, G.W., and Owens, C.M. Rigor development and meat quality of large and small broilers and the use of Allo-Kramer shear, needle puncture, and razor blade shear to measure texture. *Poult. Sci.* 84, 113, 2005.
83. Cavitt, L.C., Meullenet, J.-F.C., Xiong, R., and Owens, C.M. The relationship of razor blade shear, Allo-Kramer shear, Warner–Bratzler shear and sensory tests to changes in tenderness of broiler breast fillets. *J. Muscle Foods* 16, 223, 2005.
84. Xiong, R., Cavitt, L.C., Meullenet, J.F., and Owens, C.M. Comparison of Allo-Kramer, Warner–Bratzler and razor blade shears for predicting sensory tenderness of broiler breast meat. *J. Text. Stud.* 37, 179, 2006.
85. Lee, Y.S., Owens, C.M., and Meullenet, J.F. The application of the Meullenet-Owens-Razor-Shear (MORS) for the prediction of broiler *pectoralis major* muscle tenderness to the Instron InSpec. In *IFT Annual Meeting Book of Abstracts*, 2006.
86. Lee, Y.S., Xiong, R., Saha, A., Owens, C.M., and Meullenet, J.F. Tenderness of broiler breast fillets during long-term freezing. In *IFT Annual Meeting Book of Abstracts*, 2006.
87. Alpers, T.K. Effectiveness of blunt Meullenet-Owens razor shear (BMORS) for predicting tenderness in beef. In *IFT Annual Meeting Book of Abstracts*, 2006.
88. Alpers, T.K., Priesmeyer, T.S., and Meullenet, J.F. Meat tenderness testing. US Patent #3 602 038, 1971.
89. Hansen, L.J. Development of the Armour tenderometer for tenderness evaluation of beef carcasses. *J. Text. Stud.* 3, 146, 1972.
90. Campion, D.R., Crouse, J.D., and Dikeman, M.E. The Armour tenderometer as a predictor of cooked meat tenderness. *J. Food Sci.* 40, 886, 1975.
91. Dikeman, M.E., Tuma, H.J., Glimp, H.A., Gregory, K.E., and Allen, D.M. Evaluation of the tenderometer for predicting bovine muscle tenderness. *J. Anim. Sci.* 34, 960, 1972.
92. Carpenter, Z.L., Smith, G.C., and Butler, O.D. Assessment of beef tenderness with the Armour tenderometer. *J. Food Sci.* 37, 126, 1972.
93. Henrickson, R.L., Marsden, J.L., and Morrison, R.D. An evaluation of the Armour tenderometer for an estimation of beef tenderness. *J. Food Sci.* 37, 857, 1972.
94. Parrish Jr., F.C., Olson, D.G., Miner, B.E., Yound, R.B., and Snell, R.L. Relationship of tenderness measurements made by the Armour tenderometer to certain objective, subjective and organoleptic properties of bovine muscle. *J. Food Sci.* 38, 1214, 1973.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

95. Huffman, D.L. An evaluation of the tenderometer for measuring beef tenderness. *J. Anim. Sci.* 38, 287, 1974.
96. Tuomy, J.M. Definition and measurement of meat texture in military development and procurement. *J. Text. Stud.* 7, 5, 1976.
97. Morrow, C.T. and Mohsenin, N.N. Mechanics of a multiple needle tenderometer for raw meat. *J. Text. Stud.* 7, 115, 1976.
98. Jeremiah, L.E. and Phillips, D.M. Evaluation of a probe for predicting beef tenderness. *Meat Sci.* 55, 493, 2000.
99. Timm, R.R., Unruh, J.A., Dikeman, M.E., Hunt, M.C., Lawrence, T.E., Boyer Jr., J.E., and Marsden, J.L. Mechanical measures of uncooked beef longissimus muscle can predict sensory panel tenderness and Warner–Bratzler shear force of cooked steaks. *J. Anim. Sci.* 81, 1721, 2003.
100. Timm, R.R., Unruh, J.A., Dikeman, M.E., Hunt, M.C., Lawrence, T.E., Boyer Jr., J.E., and Marsden, J.L. Mechanical measurements of uncooked beef longissimus muscle can predict tenderness of strip loin steaks. In *Proceedings of the 55th Annual Reciprocal Meat Conference*, American Meat Science Association and National Cattlemen's Beef Association, Savoy, IL, 2002, 124.
101. Hinnergardt, L.C. and Tuomy, J.M. A penetrometer test to measure meat tenderness. *J. Food Sci.* 35, 312, 1970.
102. Huff-Lonergan, E., Baas, T.J., Malek, M., Dekkers, J.C.M., Prusa, K., and Rothschild, M.F. Correlations among selected pork quality traits. *J. Anim. Sci.* 80, 617, 2002.
103. Anonymous. *Measuring Beef Tenderness Objectively*. Lancombe Research Center, Lancombe, Alberta, Bulletin, 2nd edition, 2000, 1.
104. Nakai, H., Tanabe, R., Ando, S., Ikeda, T., and Nishizawa, M. Development of a technique for measuring tenderness in meat using a "tensipresser". In Valin, C. (Ed.), *38th International Congress of Meat Science and Technology*. Elsevier Applied Science, Barking, UK, 1992, 947.
105. Devine, C.E., Wahlgren, N.M., and Tornberg, E. Effect of rigor temperature on muscle shortening and tenderisation of restrained and unrestrained beef m. longissimus thoracicus et lumborum. *Meat Sci.* 51, 61, 1999.
106. Tornberg, E., Wahlgren, M., Brondum, J., and Engelsen, S.B. Pre-rigor conditions in beef under varying temperature- and pH-falls studied with rigometer, NMR and NIR. *Food Chem.* 69, 407, 2000.
107. Josell, A., Martinsson, L., and Tornberg, E. Possible mechanism for the effect of the RN– allele on pork tenderness. *Meat Sci.* 64, 341, 2003.
108. Wood, D.F. and Richards, J.F. Isometric tension studies on chicken pectoralis major muscle. *J. Food Sci.* 39, 525, 1974.
109. Kiessling, A., Helge Stien, L., Torslett, O., Suontama, J., and Slinde, E. Effect of pre- and post-mortem temperature on rigor in Atlantic salmon muscle as measured by four different techniques. *Aquaculture* 259, 390, 2006.
110. Swatland, H.J. Feasibility of measuring meat texture and exudate using paired hypodermic needles for rheology, spectrophotometry and electrical impedance. *J. Text. Stud.* 30, 217, 1999.
111. Swatland, H.J. Stratification of connective tissue toughness in beef roasts as assessed by simultaneous fluorometry and penetrometry. *Food Res. Int.* 39, 1106, 2006.
112. Swatland, H.J. and Findlay, C.J. On-line probe prediction of beef toughness, correlating sensory evaluation with fluorescence detection of connective tissue and dynamic analysis of overall toughness. *Food Qual. Pref.* 8, 233, 1997.
113. Swatland, H.J., Brooks, J.C., and Miller, M.F. Possibilities for predicting taste and tenderness of broiled beef steaks using an optical-electromechanical probe. *Meat Sci.* 50, 1, 1998.
114. Swatland, H.J. Stratification of toughness in beef roasts. *Meat Sci.* 77, 2, 2007.
115. Van Oeckel, M.J., Warnants, N., and Boucque, C.H. Pork tenderness estimation by taste panel, Warner–Bratzler shear force and on-line methods. *Meat Sci.* 53, 259, 1999.
116. Egelandsdal, B., Wold, J.P., Sponnich, A., Neegard, S., and Hildrum, K.I. On attempts to measure the tenderness of *longissimus dorsi* muscles using fluorescence emission spectra. *Meat Sci.* 60, 187, 2002.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

117. Meullenet, J.F., Jonville, E., Grezes, D., and Owens, C.M. Prediction of the texture of cooked poultry pectoralis major muscles by near-infrared reflectance analysis of raw meat. *J. Text. Stud.* 35, 573, 2004.
118. Park, B., Chen, Y.-R., Hruschka, W.R., Shackelford, S.D., and Koohmaraie, M. Near-infrared reflectance analysis for predicting beef longissimus tenderness. *J. Anim. Sci.* 76, 2115, 1998.
119. Park, B., Chen, Y.-R., Hruschka, W.R., Koohmaraie, M., and Shackelford, S.D. Assessment of beef tenderness using near-infrared spectroscopy. In *3rd Am. Soc. Agric. Eng.*, ASAE Annual International Meeting Technical Papers, Vol. 3, St. Joseph, MI, 1997.
120. Park, B., Chen, Y.-R., Hruschka, W.R., Shackelford, S.D., and Koohmaraie, M. Principal component regression of near-infrared reflectance spectra for beef tenderness prediction. *Trans. Am. Soc. Agric. Eng.* 44, 609, 2001.
121. Andres, S., Murray, I., Navajas, E.A., Fisher, A.V., Lambe, N.R., and Bunger, L. Prediction of sensory characteristics of lamb meat samples by near infrared reflectance spectroscopy. *Meat Sci.* 76, 509, 2007.
122. Rodbotten, R., Nilsen, B.N., and Hildrum, K.I. Prediction of beef quality attributes from early post mortem near infrared reflectance spectra. *Food Chem.* 69, 427, 2000.
123. Byrne, C.E., Downey, G., Troy, D.J., and Buckley, D.J. Non-destructive prediction of selected quality attributes of beef by near-infrared reflectance spectroscopy between 750 and 1098 nm. *Meat Sci.* 49, 399, 1998.
124. Beattie, R.J., Bell, S.J., Farmer, L.J., Moss, B.W., and Patterson, D. Preliminary investigation of the application of Raman spectroscopy to the prediction of the sensory quality of beef silverside. *Meat Sci.* 66, 903, 2004.
125. Miles, C.A. and Cutting, C.L. Changes in the velocity of ultrasound in meat during freezing. *J. Food Technol.* 9, 119, 1974.
126. Sigfusson, H., Ziegler, G.R., and Coupland, J.N. Ultrasonic monitoring of unsteady-state cooling of food products. *Trans. Am. Soc. Agric. Eng.* 44, 1235, 2001.
127. Sigfusson, H., Ziegler, G.R., and Coupland, J.N. Ultrasonic monitoring of food freezing. *J. Food Eng.* 62, 263, 2004.
128. Benedito, J., Carcel, J.A., Rossello, C., and Mulet, A. Composition assessment of raw meat mixtures using ultrasonics. *Meat Sci.* 57, 365, 2001.
129. Mulet, A., Benedito, J., Golas, Y., and Carcel, J.A. Noninvasive ultrasonic measurements in the food industry. *Food Rev. Int.* 18, 123, 2002.
130. Simal, S., Benedito, J., Clemente, G., Femenia, A., and Rossello, C. Ultrasonic determination of the composition of a meat-based product. *J. Food Eng.* 58, 253, 2003.
131. Benedito, J., Carcel, J.A., Gonzalez, R., and Sanjuan, N. Prediction of instrumental and sensory textural characteristics of mahon cheese from ultrasonic measurements. *J. Text. Stud.* 31, 631, 2000.
132. Llull, P., Simal, S., Femenia, A., Benedito, J., and Rossello, C. The use of ultrasound velocity measurement to evaluate the textural properties of sobrassada from Mallorca. *J. Food Eng.* 52, 323, 2002.
133. Llull, P., Simal, S., Benedito, J., Rossello, C., and Femenia, A. Erratum to: "Evaluation of textural properties of a meat-based product (sobrassada) using ultrasonic techniques" [*Journal of Food Engineering* 53 (2002) 279–285]. *J. Food Eng.* 55, 373, 2002.
134. Llull, P., Simal, S., Benedito, J., and Rossello, C. Evaluation of textural properties of a meat-based product (sobrassada) using ultrasonic techniques. *J. Food Eng.* 53, 279, 2002.
135. Bond, L.J. Ultrasonic measurements in food processing: Introduction and fundamentals. In *IFT Annual Meeting Book of Abstracts*. IFT Press, Chicago, IL, 2002.
136. Park, B. and Chen, Y.-R. Ultrasonic shear wave characterization in beef longissimus muscle. *Trans. Am. Soc. Agric. Eng.* 40, 229, 1997.
137. Park, B., Whittaker, A.D., Miller, R.K., and Hale, D.S. Ultrasonic spectral analysis for beef sensory attributes. *J. Food Sci.* 59, 697, 1994.
138. Abouelkaram, S., Suchorski, K., Buquet, B., Berge, P., Culioli, J., Delachartre, P., and Basset, O. Effects of muscle texture on ultrasonic measurements. *Food Chem.* 69, 447, 2000.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

139. Park, B., Thane, B.R., and Whittaker, A.D. Ultrasonic image analysis for beef tenderness. In *1836th Proc. SPIE Int. Soc. Opt. Eng.*, SPIE, Boston, MA, 1993, 120.
140. Ayadi, A., Culioli, J., and Abouelkaram, S. Sonoelasticity to monitor mechanical changes during rigor and ageing. *Meat Sci.* 76, 321, 2007.
141. Jeyamkondan, S., Kranzler, G., Anand, L., Morgan, J.B., and Brooks, J.C. Predicting beef tenderness from textural features. In *Am. Soc. Agric. Eng. Ann. Int. Meet.*, ASAE, Chicago, IL, 2002.
142. Basset, O., Dupont, F., Hernandez, A., Odet, C., Abouelkaram, S., and Culioli, J. Texture image analysis: application to the classification of bovine muscles from meat slice images. *Opt. Eng.* 38, 1950, 1999.
143. Basset, O., Buquet, B., Abouelkaram, S., Delachartre, P., and Culioli, J. Application of texture image analysis for the classification of bovine meat. *Food Chem.* 69, 437, 2000.
144. Xing, J., Ngadi, M., Gunenc, A., Prasher, S., and Gariepy, C. Use of visible spectroscopy for quality classification of intact pork meat. *J. Food Eng.* 82, 135, 2007.
145. Chandraratne, M.R., Samarasinghe, S., Kulasiri, D., and Bickerstaffe, R. Prediction of lamb tenderness using image surface texture features. *J. Food Eng.* 77, 492, 2006.
146. Chandraratne, M.R., Kulasiri, D., and Samarasinghe, S. Classification of lamb carcass using machine vision: comparison of statistical and neural network analyses. *J. Food Eng.* 82, 26, 2007.
147. Zheng, C., Sun, D.W., and Zheng, L. Classification of tenderness of large cooked beef joints using wavelet and Gabor textural features. *Trans. ASABE* 49, 1447, 2006.
148. Brosnan, T. and Sun, D.W. Improving quality inspection of food products by computer vision—a review. *J. Food Eng.* 61, 3, 2004.
149. Zheng, C., Sun, D.W., and Zheng, L. Correlating colour to moisture content of large cooked beef joints by computer vision. *J. Food Eng.* 77, 858, 2006.
150. Tan, J. Meat quality evaluation by computer vision. *J. Food Eng.* 61, 27, 2004.
151. Goni, M.V., Beriain, M.J., Indurain, G., and Insausti, K. Predicting longissimus dorsi texture characteristics in beef based on early post-mortem colour measurements. *Meat Sci.* 76, 38, 2007.
152. Belk, K.E., Scanga, J.A., Wyle, A.M., and Smith, G.C. Prediction of beef palatability using instruments. In *Proceedings of the Beef Improvement Federation Convention*, Beef Improvement Federation, 2000, 1.
153. Wheeler, T.L., Vote, D., Leheska, J.M., Shackelford, S.D., Belk, K.E., Wulf, D.M., Gwartney, B.L., and Koohmaraie, M. The efficacy of three objective systems for identifying beef cuts that can be guaranteed tender. *J. Anim. Sci.* 80, 3315, 2002.
154. Li, J., Tan, J., and Martz, F.A. Predicting beef tenderness from image texture features. In *11th Am. Soc. Agric. Eng.*, ASAE Annual International Meeting Technical Papers, Vol. 1, St. Joseph, MI, 1997.
155. Li, J., Tan, J., and Shatadal, P. Classification of tough and tender beef by image texture analysis. *Meat Sci.* 57, 341, 2001.
156. Del Moral, F.G., O'Valle, F., Masseroli, M., and Del Moral, R.G. Image analysis application for automatic quantification of intramuscular connective tissue in meat. *J. Food Eng.* 81, 33, 2007.
157. Tian, Y.Q., McCall, D.G., Dripps, W., Yu, Q., and Gong, P. Using computer vision technology to evaluate the meat tenderness of grazing beef. *Food Aust.* 57, 322, 2005.
158. Tian, Y.Q., Tan, J., McCall, D.G., Gong, P. www.cnr.berkeley.edu/~ytian/tian_personal/Yong_Tian.files/meatpaper.pdf, Accessed on September 2, 2006.
159. Chandraratne, M.R., Kulasiri, D., and Samarasinghe, S. Classification of lamb carcass using machine vision: comparison of statistical and neural network analyses. *J. Food Eng.* 82, 26, 2007.
160. Kroger, C., Bartle, C.M., West, J.G., Purchas, R.W., and Devine, C.E. Meat tenderness evaluation using dual energy X-ray absorptiometry (DEXA). *Comp. Elect. Agric.* 54, 93, 2006.
161. Gonzalez, R., Montoya, I., and Carcel, J. Review: The use of electromyography on food texture assessment. *Food Sci. Technol. Int.* 7, 461, 2001.
162. Ophir, J., Miller, R.K., Ponnekanti, H., Cespedes, I., and Whittaker, A.D. Elastography of beef muscle. In Valin, C. (Ed.), *38th International Congress of Meat Science and Technology.* Elsevier Applied Science, Barking, UK, 1992, 153.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

163. Ophir, J., Miller, R.K., Ponnekanti, H., Cespedes, I., and Whittaker, A.D. Elastography of beef muscle. *Meat Sci.* 36, 239, 1994.
164. Berg, E.P., Kallel, F., Hussain, F., Miller, R.K., Ophir, J., and Kehtarnavaz, N. The use of elastography to measure quality characteristics of pork semimembranosus muscle. *Meat Sci.* 53, 31, 1999.
165. Chandrasekhar, R., Ophir, J., Krouskop, T., and Ophir, K. Elastographic image quality vs. tissue motion in vivo. *Ultrasound Med. Biol.* 32, 847, 2006.
166. Huang, Y., Lacey, R.E., and Whittaker, A.D. Neural network prediction modeling based on elastographic textural features for meat quality evaluation. *Trans. Am. Soc. Agric. Eng.* 41, 1173, 1998.
167. Huang, Y., Lacey, R.E., Moore, L.L., Miller, R.K., Whittaker, A.D., and Ophir, J. Wavelet textural features from ultrasonic elastograms for meat quality prediction. *Trans. Am. Soc. Agric. Eng.* 40, 1741, 1997.
168. Kang, Y.B., Oida, T., Jung, D.Y., Fukuma, A., Azuma, T., Okamoto, J., Takizawa, O., Matsuda, T., and Tsutsumi, S. Non-invasive measurement of in-vivo elasticity of skeletal muscles with MR-elastography. *Key Eng. Mater.* 901, 342, 2007.
169. Bensamoun, S.F., Ringleb, S.I., Littrell, L., Chen, Q., Brennan, M., Ehman, R.L., and An, K.N. Determination of thigh muscle stiffness using magnetic resonance elastography. *J. Magn. Reson. Imaging* 23, 242, 2006.
170. Marburger, R.M., Keeton, J.T., Maddock, R.J., and Moreira, R.G. Biomechanical characterization of meat tenderness. In *IFT Annual Meeting Book of Abstracts*. IFT Press, Chicago, IL, 2000.
171. Campo, M.M., Santolaria, P., Sanudo, C., Lepetit, J., Olleta, J.L., and Panea, B. Assessment of breed type and ageing time effects on beef meat quality using two different texture devices. *Meat Sci.* 55, 371, 2000.
172. Lepetit, J. and Hamel, C. Correlations between successive measurements of myofibrillar resistance of raw longissimus dorsi muscle during ageing. *Meat Sci.* 49, 249, 1998.
173. Luckett, R.L., Bidner, T.D., and Turner, J.W. The tenderometer as a measure of beef tenderness. *J. Anim. Sci.* 34, 347, 1972.
174. Luckett, R.L., Bidner, T.D., Icaza, E.A., and Turner, J.W. Tenderness studies in straightbred and crossbred steers. *J. Anim. Sci.* 40, 468, 1975.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 3

Techniques for Sampling and Identification of Volatile Compounds Contributing to Sensory Perception

Saskia M. van Ruth

Contents

3.1 Introduction 40
3.2 Sampling of Volatiles Available for Sensory Perception 41
3.2.1 Headspace Sampling 42
3.2.1.1 Static Headspace Sampling 42
3.2.1.2 Dynamic Headspace Sampling 42
3.2.2 *In Vitro* Sampling (Mouth Analogs) 43
3.2.3 *In Vivo* Sampling 43
3.3 Identification of the Volatile Compounds Contributing to Sensory Perception: GC-O 44
3.4 Applications to Meat Flavor: Sampling and Identification of Volatiles Contributing to Sensory Perception 45
3.4.1 Extraction—GC-O 45
3.4.2 Static Headspace Sampling—GC-O 45
3.4.3 Dynamic Headspace Sampling—GC-O Analysis 45
3.4.4 Mouth Analog Sampling—GC-O Analysis 45
3.4.5 *In Vivo* Sampling 45

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

3.5 Conclusions 46
References 46

3.1 Introduction

Taste, aroma, and texture contribute to the palatability of meat. Flavor is an important sensory aspect of the overall acceptability of meat products [1]. There is no evidence that the acceptability of particular meat products is related to the ability to perceive particular odor or flavor qualities. For instance, although consumers in Asian markets show a poor acceptability of sheep meat odor, they are more sensitive to specific qualities. It is likely that in countries whose diet include a particular type of meat, a long history of consumption promotes a preference for the same flavor qualities that are disliked by those who do not regularly consume that type of meat [2]. These qualities, however, can be related to certain odor-active compounds [3]. Variation in beef quality is large and is due to many factors, such as genetic differences, as well as sex, age, management, and nutrition. These factors interact with one another [4]. The consumer's decision to purchase beef is based on the perception of health and a variety of sensory traits including color, tenderness, juiciness, and odor/flavor [5]. It is therefore worthwhile considering variations in meat quality at the consumer level, with respect to both sensory traits and health aspects.

As flavor is an important component of the quality of meat, there has been much research aimed at understanding the chemistry of meat flavor, and at determining those factors during the production and processing of meat that influence flavor quality. Meat flavor is thermally derived, since uncooked meat has little or no aroma and only a blood-like taste. During cooking, a complex series of thermally induced reactions occur between nonvolatile components of lean and fatty tissues, resulting in a large number of reaction products. Although the flavor of cooked meat is influenced by compounds contributing to the sense of taste, it is the volatile compounds, formed during cooking, that determine the aroma attributes, contributing to the characteristic flavors of meat [6]. Over 1000 volatile compounds have been reported in the literature [7]. Volatile compounds in cooked meat are derived from both lipid- and water-soluble precursors. They provide roast, boiled, fatty, and species-related flavors, as well as the characteristic meaty aromas associated with all cooked meats. Thermal degradation of lipid provides compounds that give fatty aromas to cooked meat and compounds that determine the flavors of the different species. The Maillard reaction is primarily responsible for the large number of heterocyclic compounds that have been found in the volatiles of cooked meat and are responsible for savory, roast, and boiled flavors. Pentoses, in particular ribose from meat ribonucleotides, and the sulfur-containing amino acid, cysteine, are important precursors for these reactions in meat. Furanthiols and furan sulfides and disulfides are very important flavor compounds, which have exceptionally low odor threshold values, and are responsible for characteristic meaty aromas. Compounds formed during the Maillard reaction may also react with other components of meat, adding new compounds to the complex profile of aroma compounds. For example, aldehydes and other carbonyls formed during lipid oxidation react readily with Maillard intermediates. Such interactions give rise to additional aroma compounds, but they also modify the overall profile of compounds contributing to meat flavor [6].

The presence of volatile compounds in meat is undoubtedly affected by the animal feeding system. The presence of certain classes of compounds, which are enhanced by a type of diet, can be identified. The duration of the treatment plays an important role in the accumulation of fat volatiles in ruminant meat. Concentrate-based diets produce high amounts of BCFA and lactones in ruminant meat, whereas aldehydes are markedly enhanced by fat-enriched diets.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Sesquiterpenes, 2,3-octanedione, and skatole are evidently associated with grass feeding systems, although some controversy exists among various studies. Moreover, the presence of secondary compounds in the diet could affect the biosynthesis of some volatiles. This is the case of dietary condensed tannins on skatole production [8].

Although many volatile compounds have been identified in cooked meat, it is well accepted that only a limited number of volatile compounds actually contribute to the overall aroma. In addition, it is known that some powerful odorants found in meat systems exist at concentrations too low to allow their identification by the usual gas chromatography–mass spectrometry (GC-MS) procedures [9]. Therefore, alternative approaches are required to understand meat flavor/aroma and to identify its odor-active compounds. Gas chromatography–olfactometry (GC-O) is a useful and powerful tool in aroma research. Various techniques are available to identify and rank odorants [10].

Flavor is an interaction between the food and the consumer, and not a property of the food alone. So, no study on flavor is complete unless the consumer is considered as well as the chemistry and physics of the food. The perception of flavor is not a single event but a dynamic process, involving a series of events, and every step must be considered if we are to truly understand flavor. When food is taken into the mouth, volatile and nonvolatile compounds are released from the food and must transfer to the receptors before there can be any sensation. Therefore, there will be a typical delay before anything happens, then a sharp rise in the concentrations of the stimulating molecules at the receptors, followed by a slower decline in concentrations. After swallowing, the decline will continue, possibly very slowly, allowing for a long aftertaste, until the stimulating molecules have all diffused away from the receptors [11]. Simultaneously, there are short-term fluctuations in the concentrations carried to the olfactory receptors, caused by breathing [12]. On the next bite, the sequence is repeated. Overlaid on this physical process of mass transfer, there is a process of continual sensory adaptation and recovery. Thus the apparently simple process of tasting a food or beverage is in fact composed of a sequence of complex processes, any of which can affect the sensation. For a real understanding of food flavor, such a dynamic process must be matched with dynamic research methods. Conventional sensory analysis gives a kind of integral or time-average of the total sensation. Chemical methods such as analysis of distilled or headspace volatiles provide measure of the compounds available as potential stimulants [11]. The truly dynamic methods provide some degree of time resolution of the changes in the stimulating molecules, or of the sensation [13].

3.2 Sampling of Volatiles Available for Sensory Perception

Distillation and extraction are common procedures to sample volatile compounds. They normally aim to analyze the totality of the volatiles present in a food and may not represent closely the volatiles available for perception when a food is consumed. Headspace analysis methods, whether static or dynamic, provide results that should more accurately represent the real consumption of food. To obtain data that better reflect the pattern of volatiles present at the olfactory receptors during consumption, a number of devices have been proposed that simulate in large or small measure the process of eating. These are variants of dynamic headspace analysis. The systems are often combined with some form of time-resolved sampling. Furthermore, systems have been developed to allow sampling of the headspace from the nose or mouth, on the assumption that this better reflects the volatiles that are available for perception [11]. In the following sections, headspace, *in vitro* (mouth analogs), and *in vivo* sampling techniques are described in greater detail.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

3.2.1 Headspace Sampling

An important characteristic of volatile flavor compounds is that they exhibit sufficient vapor pressure to be present in the gas phase at a concentration detectable by the olfactory system. This basis of aroma isolation appears most reasonable. It is understandable that many aroma isolation techniques are based on volatility. Many of these techniques are focused on the volatility of the compounds in the system to be studied, and not on the concentration of the compounds in the food. The amounts of aroma compounds in the headspace do not follow in order of volatility (vapor pressure) of the pure compounds but, instead, depends on their vapor pressure over the food system.

3.2.1.1 Static Headspace Sampling

Many compounds exist as gases at the temperature at which they are being sampled or have sufficiently high vapor pressure to evaporate and produce a gas-phase solution. In these cases, the gas itself may be injected into a gas chromatograph, either by syringe or by transferring a known volume of vapor from a sample loop attached to a valve. The amount of gas that can be injected is limited by the capacity of the injection port and the analytical column. In practical terms, injections are almost always in the low milliliter range, with sizes of 0.1–2.0 mL being typical [14].

If a complex material, such as a food, is placed into a sealed vial and allowed to stand, the volatile compounds in the sample matrix will leave the sample and distribute over the headspace around it. The concentration of the compounds in the headspace depends on several factors, such as the concentration in the original sample, the volatility of the compound, the solubility of that compound in the sample matrix, the temperature of the sample, and combination of the size of the vial and the time the sample has been inside in the vial [14]. At equilibrium, the relationship between the concentration of the volatile compound in the product phase and in the vapor phase can be expressed by Henry's law. This law states that the mass of vapor dissolved in a certain volume of solvent is directly proportional to the partial pressure of the vapor that is in equilibrium with the solution [15]. Static headspace isolation normally involves taking a sample of the equilibrium headspace surrounding a sample. This can be directly injected onto a gas chromatographic column. In classical static headspace analysis, volatiles are removed without any attempt to simulate the conditions in the mouth during eating. Therefore, amounts determined do not necessarily represent the compounds and the quantities available for perception during eating. Classical headspace analysis is probably more closely related to the odor perceived as food approaches the mouth before eating [16].

More recently, solid-phase micro-extraction (SPME) has been developed for headspace sampling. It involves extraction of volatile compounds out of the headspace onto a fused-silica fiber coated with a polymeric phase. After equilibration, the fiber containing the adsorbed or absorbed analytes is thermally desorbed and subjected to analysis [17]. It should be kept in mind that a second equilibrium between headspace and fiber is involved that may affect how well the sample reflects the actual headspace composition.

3.2.1.2 Dynamic Headspace Sampling

In dynamic headspace analysis, a flow of gas is passed over the food to strip off volatiles, which results in a greater yield of material for analysis than in static headspace isolation. In a separate part of the apparatus, volatiles are trapped from the gas stream. The headspace of the sample is

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

continually renewed. Often the sample is stirred or otherwise agitated to increase mass transfer from the sample into the headspace [18]. Normally, a solid adsorbent is used to trap the volatiles, such as charcoal, Porapak Q, Chromosorb 101–105, or Tenax, and they are usually thermally desorbed before gas chromatographic analysis. Dynamic headspace methods permit analyses with minimal introduction of artifacts developed or introduced during sampling [19]. The thermal desorption of the compounds from the absorbent, although convenient and rapid, has the disadvantage of causing molecular change in some important unstable aroma compounds, such as (*Z*)-3-hexenal, alkadienals, and certain sulfur compounds. This may be due to the elevated temperatures applied during desorption and the metal parts frequently used in thermal desorption units. In the actual eating process, equilibrium is not likely, if ever attained in the mouth. The dynamic mode seems, therefore, more closely aligned with what happens in the mouth during eating than static headspace analysis.

3.2.2 In Vitro *Sampling (Mouth Analogs)*

Mouth analogs have been developed to mimic aroma release in the mouth more precisely and to consider changes in aroma release during eating. In actual eating situations, aroma concentrations are determined kinetically rather than thermodynamically [20]. Only a few instrumental methods of aroma release have incorporated the crushing, mixing, dilution, and temperature conditions required to simulate aroma release in the mouth from solid foods. Lee III [21] reported an instrumental technique for measuring dynamic flavor release. A mass spectrometer was coupled with a dynamic headspace system, that is, a vial with several small metal balls that simulated mastication. van Ruth et al. [22] reported a model mouth system that consisted of a thermostated glass flask with a volume of 70 mL, with the option of (artificial) saliva addition. A plunger making screwing movements simulated mastication. This is one of the few mouth analogs that has been validated by comparison with the *in vivo* volatile flavor concentrations [23]. Naβl et al. [24] described a "mouth imitation chamber," which consisted of a large volume thermostated vessel with a stirrer, while artificial saliva was added to the system. Roberts and Acree [20] reported a "retronasal aroma simulator"—a purge-and-trap device made from a blender. It simulated mouth conditions by regulating the temperature to 37°C, adding artificial saliva, and using mechanical forces. Withers et al. [25] reported a simple mouth analog for drinks, which consisted of a glass flask filled with liquid sample and artificial saliva with glass beads, which was situated in a shaking water bath.

3.2.3 In Vivo *Sampling*

In the period 1985–2000, techniques were developed to measure the release of volatile compounds *in vivo*, that is, in the mouth and nose of subjects. The advantage of these techniques over model systems is that the data reflect volatile concentrations as they are during perception. However, one has to deal with the fact that the results are highly variable, because large inter-individual variations in volatile flavor release exist.

A simple way of measuring volatile release from foods is to analyze compounds in the expired air drawn from the nose of subjects consuming (model) foods. In the beginning of the nineties, attention turned to analyses that concentrated the volatiles over short time periods from the sample before analysis. Volatiles from expired breath were collected for certain time intervals (e.g., 15 s) either onto lengths of capillary tubes, by means of cryotrapping or by trapping on absorption materials, such as Tenax [26], and were subsequently analyzed.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Real-time analysis requires a detector capable of continuously monitoring compounds in air with a high temporal resolution. Several types of systems have been developed to allow real-time gas-phase analysis. A membrane separator method using direct MS was developed by Soeting and Heidema [27] for determining aroma profiles in the expired air of assessors as a function of time. Linforth and Taylor modified an atmospheric pressure chemical ionization source of a mass spectrometer to allow the introduction of gas-phase samples [28]. It is a soft ionization technique, which adds a proton to the compound of interest and does not normally induce fragmentation. Consequently, compounds present in the breath are monitored in selected ion mode, further enhancing sensitivity. Lindinger et al. [29] reported an online monitoring technique for measurement of volatile organic compounds based on proton transfer reaction mass spectrometry (PTR-MS). PTR-MS links the idea of chemical ionization introduced by Munson and Field in 1966 [30] with the swarm technique of flow-drift-tube type, invented by Ferguson and coworkers in the early 1970s [31]. Proton transfer reactions are used to induce chemical ionization of the vapors to be analyzed. The sample gas is continuously introduced into a drift tube, where it is mixed with H_3O^+ ions formed in a hollow cathode ion source. Volatile compounds that have proton affinities higher than water (>166.5 kcal/mol) are ionized by proton transfer from H_3O^+, mass analyzed in a quadrupole mass spectrometer, and eventually detected as ion counts/s (cps) by a secondary electron multiplier [32]. The outcome is either a mass-resolved fingerprint of the total volatile profile of a sample or a time-resolved profile for a selection of masses. PTR-MS is interesting for time-resolved analysis because it (i) requires no pretreatment of the sample, (ii) allows rapid measurements (typically 0.2 s/mass), and (iii) is extremely sensitive.

3.3 Identification of the Volatile Compounds Contributing to Sensory Perception: GC-O

The distinction between odor-active compounds and the whole range of volatiles present in a particular food product is an important task in flavor analysis. An interesting approach is sniffing the gas chromatographic effluent of a representative isolate of volatile compounds of a food to associate odor activity with the eluting compounds. Many of the "chemical" detectors are not as sensitive as the human nose for many odor-active compounds. Combining human perception of odor and chromatographic separation of compounds, that is, GC-O, offers great possibilities. The chromatographic separation of compounds can be a difficult task, which depends primarily on the complexity of the flavor. However, the registration and quantification of the sensory perception are also two of the important challenges of the technique.

Most methods aim to rank the volatile flavor compounds detected in order of sensory importance. The three important types of methods used are the dilution to detection threshold method, the detection frequency method, and the perceived intensity method. In the dilution analysis, an extract is diluted, and each dilution is sniffed until any odor is no longer detected. The last dilution at which a compound is detected is a measure for its odor potency [33,34]. The detection frequency method [35,36] is based on the number of assessors in a group of 6–12 assessors detecting an odor in the GC effluent simultaneously (detection frequency). The detection frequency is a measure for the sensory importance of a compound. The third group of GC-O techniques involves intensity methods. These methods measure the odor intensity of a compound in the GC effluent. They include the posterior intensity method [37,38], the cross-modality matching finger span technique [39], and the time-intensity methods [40].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

3.4 Applications to Meat Flavor: Sampling and Identification of Volatiles Contributing to Sensory Perception

3.4.1 Extraction—GC-O

The odor-active compounds of cooked meats have been widely investigated using GC-O, but mostly using (solvent) extraction techniques for sampling. Examples of studies in which extractions were carried out followed by dilution analysis are those on cooked beef [41,42] as well as on pork and chicken [43,44]. Specht and Baltes [45] identified odor-active compounds in a similar manner in shallow-fried beef. Generally, compounds with higher boiling temperatures are sampled with this type of extraction.

3.4.2 Static Headspace Sampling—GC-O

An example of a study in which headspace sampling was used is the one of Carrapiso et al. [10]. They characterized the odor-active compounds of dry-cured ham using the detection frequency technique for GC-O evaluation. Compounds included aldehydes, ketones, esters, sulfur-containing compounds, nitrogen-containing compounds, and an alcohol. Moon et al. [46] reported a study on the comparison of different types of cooked beef. In this study, headspace sampling was applied using SPME. The odor-active compounds were identified by GC-O using the detection frequency analysis.

3.4.3 Dynamic Headspace Sampling—GC-O Analysis

Dynamic headspace sampling in combination with GC-O dilution analysis has also been applied to fermented sausages to evaluate various sampling procedures, such as molecular distillation, high vacuum distillation, and vacuum steam distillation [47]. Similarly, dynamic headspace sampling was compared to vacuum simultaneous distillation-solvent extraction in combination with GC-O dilution analysis for the determination of the odor-active compounds of alligator meat [48].

3.4.4 Mouth Analog Sampling—GC-O Analysis

Very few studies have been reported using a mouth analog for sampling. Machiels et al. determined the odor-active compounds in two commercial Irish beef meats [49] as well as in meat of differently fed bulls [50] using a mouth analog for sampling and the detection frequency technique for GC-O evaluation.

3.4.5 In Vivo *Sampling*

No studies on the analysis of odor-active compounds of meat using *in vivo* sampling were reported in the literature according to the author's knowledge. Neither was any meat study found using *in vivo* real-time analysis of meat volatiles or a form of intensity rating in GC-O analysis.

To summarize, most studies in which odor-active compounds have been analyzed in meat have reported sampling in the form of extractions or dynamic headspace analysis usually in combination with GC-O dilution analysis. Static headspace sampling and the use of mouth analogs have been applied in combination with GC-O analysis, using the detection frequency methodology.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

3.5 Conclusions

For sampling of volatile compounds that contribute to sensory perception various techniques are available, such as static headspace sampling, dynamic headspace sampling, the use of mouth analogs, and *in vivo* samplings. GC-O analysis is an interesting technique for identification of the odor-active volatile compounds of food samples. Although most odor-active compounds in meat have been assessed by GC-O after a type of (solvent or vacuum) extraction, it is especially interesting to evaluate these characteristics of compounds at concentrations and in ratios that represent consumption conditions. Some studies report static or dynamic headspace sampling or the application of mouth analogs. The use of *in vivo* measurements for meat analysis with or without the combination of GC-O has not received attention yet. Therefore, this type of sampling may be an interesting way forward in meat flavor analysis.

References

1. Matsuishi, M., Igeta, M., Takeda, S., and Okitani, A. Sensory factors contributing to the identification of the animal species of meat. *J. Food Sci*. 69, 218–220. 2004.
2. Crandall, C. S. The liking of foods as a result of exposure: eating doughnuts in Alaska. *J. Soc. Psychol*. 125, 187–194. 1985.
3. Prescott, J., Young, O., and O'Neill, L. The impact of variations in flavour compounds on meat acceptability: a comparison of Japanese and New Zealand consumers. *Food Qual. Pref*. 12, 257–264. 2001.
4. Raes, K., Balcaen, A., Dirinck, P., De Winne, A., Claeys, E., Demeyer, D., and De Smet, S. Meat quality, fatty acid composition and flavour analysis in Belgian retail beef. *Meat Sci*. 65, 1237–1246. 2003.
5. Verbeke, W. and Viaene, J. Beliefs, attitude and behaviour towards fresh meat consumption in Belgium: empirical evidence from a consumer survey. *Food Qual. Pref*. 10, 437–445. 1999.
6. Mottram, D. S. Flavour formation in meat and meat products: a review. *Food Chem*. 62, 415–424. 1998.
7. Maarse, H. and Visscher, C. A. *Volatile Compounds in Food—Qualitative and Quantitative Data*. 7th edn. Zeist: TNO-CIVO. 1996.
8. Vasta, V. and Priolo, A. Ruminant fat volatiles as affect by diet. A review. *Meat Sci*. 73, 218–228. 2006.
9. Chevance, F. F. V. and Farmer, L. J. Identification of major volatile odor compounds in frankfurters. *J. Agric. Food Chem*. 47, 5151–5160. 1999.
10. Carrapiso, A. I., Ventanas, J., and García, C. Characterization of the most odor-active compounds of Iberian ham headspace. *J. Agric. Food Chem*. 50, 1996–2000. 2002.
11. Piggott, J. R. Dynamism in flavour science and sensory methodology. *Food Res. Int*. 33, 191–197. 2000.
12. Baek, I., Linforth, R.S.T., Blake, A., and Taylor, A. J. Sensory perception is related to the rate of change of volatile concentration in-nose during eating of model gels. *Chem. Senses* 24, 155–160. 1999.
13. Dijksterhuis, G. B. Dynamic sensory methods: some applications and developments. In *Cost 96 Symposium: Food and Flavour*, Udine, Italy, 23–24 September 1999. 1999.
14. Wampler, T. P. Analysis of food volatiles using headspace-gas chromatographic techniques. In *Techniques for Analyzing Food Aroma*, ed. R. Marsili, 27–58. New York: Marcel Dekker. 1997.
15. Morris, J. G. *A Biologist's Physical Chemistry*, London: Edward Arnold. 1968.
16. Taylor, A. J. Volatile flavor release from foods during eating. *Crit. Rev. Food Sci. Nutr*. 36, 765–784. 1996.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

17. Machiels, D. and Istasse, L. Evaluation of two commercial solid-phase microextraction fibres for the analysis of target aroma compounds in cooked beef meat. *Talanta* 61, 529–537. 2003.
18. Sucan, M. K., Fritz-Jung, C., and Ballam, J. Evaluation of purge-and-trap parameters optimization using a statistical design. In *Flavor Analysis. Developments in Isolation and Characterisation*, eds C. J. Mussinan and M. J. Morello, 22–37. Washington: American Chemical Society. 1998.
19. Teranishi, R. Challenges in flavor chemistry: an overview. In *Flavor Analysis. Developments in Isolation and Characterization*, eds C. J. Mussinan and M. J. Morello, 1–6. Washington: American Chemical Society. 1998.
20. Roberts, D. D. and Acree, T. E. Simulation of retronasal aroma using a modified headspace technique: investigating the effects of saliva, temperature, shearing, and oil on flavor release. *J. Agric. Food Chem*. 43, 2179–2186. 1995.
21. Lee III, W. E. A suggested instrumental technique for studying dynamic flavor release from food products. *J. Food Sci*. 51, 249–250. 1986.
22. van Ruth, S. M., Roozen, J. P., and Cozijnsen, J. L. Comparison of dynamic headspace mouth model systems for flavour release from rehydrated bell pepper cuttings. In *Trends in Flavour Research*, eds H. Maarse and D. G. van der Heij, 59–64. Amsterdam: Elsevier. 1994.
23. van Ruth, S. M. and Roozen, J. P. Influence of mastication and artificial saliva on aroma release in a model mouth system. *Food Chem*. 71, 339–345. 2000.
24. Naβl, K., Kropf, F., and Klostermeyer, H. A method to mimic and to study the release of flavour compounds from chewed food. *Z. Lebensm. Unters. –Forsch*. 201, 62–68. 1995.
25. Withers, S. J., Conner, J. M., Piggott, J. R., and Paterson, A. A simulated mouth to study flavour release from alcoholic beverages. In *Food Science and Technology Cost 96, Interaction of Food Matrix with Small Ligands Influencing Flavour and Texture,* volume 3, ed. P. Schieberle, 13–18. Luxembourg: Office for Official Publications of the European Communities. 1998.
26. Roozen, J. P. and Legger-Huysman, A. Sensory analysis and oral vapour gas chromatography of chocolate flakes. In *Aroma. Perception, Formation, Evaluation*, eds M. Rothe and H.-P. Kruse, 627–632. Potsdam-Rehbrücke: Eigenverlag Deutsches Institut für Ernährungsforschung. 1995.
27. Soeting, W. J. and Heidema, J. A mass spectrometric method for measuring flavour concentration/time profiles in human breath. *Chem. Senses* 13, 607–617. 1988.
28. Linforth, R. S. T. and Taylor, A. J. Measurement of volatile release in the mouth. *Food Chem*. 48, 115–120. 1993.
29. Lindinger, W., Hansel, A., and Jordan, A. On-line monitoring of volatile organic compounds at pptv levels by means of Proton Transfer Reaction Mass Spectrometry (PTR-MS). Medical applications, food control and environmental research. *Int. J. Mass Spectrom. Ion Proc*. 173, 191–241. 1998.
30. Munson, M. S. B. and Field, F. H. Chemical ionization mass spectrometry. I. General introduction. *J. Am. Chem. Soc*. 88, 2621–2630. 1966.
31. McFarland, M., Albritton, D. L., Fehsenfeld, F. C., Ferguson, E. E., and Schmeltekopf, A. L. Flow-drift technique for ion mobility and ion-molecule reaction rate constant measurements. II. Positive ion reactions of N+, O+, and H with O2 and O+ with N2 from thermal to [inverted lazy s]2 eV. *J. Chem. Phys*. 59, 6620–6628. 1973.
32. Aprea, E., Biasioli, F., Gasperi, F., Märk, T. D., and van Ruth, S. In vivo monitoring of strawberry flavor release from model custards: effect of texture and oral processing. *Flav. Fragr. J*. 21, 53–58. 2006.
33. Acree, T. E., Barnard, J., and Cunningham, D. A procedure for the sensory analysis of gas chromatographic effluents. *Food Chem*. 14, 273–286. 1984.
34. Ullrich, F. and Grosch, W. Identification of most intense volatile flavour compounds formed during autoxidation of linoleic acid. *Z. Lebensm. Unters. –Forsch*. 184, 277–282. 1987.
35. Linssen, J. P. H., Janssens, J. L. G. M., Roozen, J. P., and Posthumus, M. A. Combined gas chromatography and sniffing port analysis of volatile compounds of mineral water packed in polyethylene laminated packages. *Food Chem*. 46, 367–371. 1993.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

36. Pollien, P., Ott, A., Montigon, F., Baumgartner, M., Rafael Muňoz-Box, R., and Chaintreau, A. Hyphenated headspace-gas chromatography-sniffing techniques: screening of impact odorants and quantitative aromagram comparisons. *J. Agric. Food Chem*. 45, 2630–2637. 1997.
37. Berdagué, J. L., Tournayre, P., and Cambou, S. Novel multi-gas chromatography-olfactometry device and software for the identification of odour active compounds. *J. Chromatogr. A* 1146, 85–92. 2007.
38. Le Guen, S., Prost, C., and Demaimay, M. Critical comparison of three olfactometric methods for the identification of the most potent odorants in cooked mussels (*Mytilus edulis*). *J. Agric. Food Chem*. 48, 1307–1314. 2000.
39. Etievant, P. X., Callement, G., Langlois, D., Issanchou, S., and Coquibus, N. Odor intensity evaluation in gas chromatograpy-olfactometry by finger span method. *J. Agric. Food Chem*. 47, 1673–1680. 1999.
40. Miranda-Lopez, R., Libbey, L. M., Watson, B. T., and McDaniel, M. R. Odor analysis of Pinot noir wines from grapes of different maturities by a gas chromatography-olfactometry technique (Osme). *J. Food Sci*. 57, 985–993, 1019. 1992.
41. Gasser, U. and Grosch, W. Identification of volatile flavour compounds with high aroma values from cooked beef. *Z. Lebensm. Unters. –Forsch.* 186, 489–494. 1988.
42. Cerny, C. and Grosch, W. Evaluation of potent odorants in roasted beef by aroma extract dilution analysis. *Z. Lebensm. Unters. –Forsch*. 194, 322–325. 1992.
43. Werkhoff, P., Bruening, J., Emberger, R., Guentert, M., and Hopp, R. Flavour chemistry of meat volatiles: new results on flavor components from beef, pork and chicken. In *Recent Development in Flavor and Fragrance Chemistry: Proceedings of the 3rd International Haarmann & Reimer Symposium*, 183–213. Holzminden: VCH. 1993.
44. Gasser, U. and Grosch, W. Primary odourants of chicken broth. *Z. Lebensm. Unters. –Forsch*. 190, 3–8. 1990.
45. Specht, K. and Baltes, W. Identification of volatile flavour compounds with high aroma values from shallow-fried beef. *J. Agric. Food Chem*. 42, 2246–2253. 1994.
46. Moon, S.-Y., Cliff, M. A., and Li-Chan, E. C. Y. Odour active components of simulated beef flavour analysed by solid phase microextraction and gas chromatography-mass spectrometry and –olfactometry. *Food Res. Int*. 39, 294–308. 2006.
47. Schmidt, S. and Berger, R. G. Aroma compounds in fermented sausages of different origins. *Lebensm. –Wiss. Technol*. 31, 559–567. 1998.
48. Cadwallader, K. R., Baek, H. H., Chung, H. Y., and Moody, M. W. Contribution of lipid-derived components to the flavour of alligator meat. In *Lipids in Food Flavors, ACS Symposium Series* 558, 186–195. 1994.
49. Machiels, D., van Ruth, S. M., Posthumus, M. A., and Istasse, L. Gas chromatography-olfactometry analysis of the volatile compounds of two commercial Irish beef meats. *Talanta* 60, 755–764. 2003.
50. Machiels, D., Istasse, L., and van Ruth, S. M. Gas chromatography-olfactometry analysis of beef meat originating from differently fed Belgian Blue, Limousin and Aberdeen Angus bulls. *Food Chem*. 86, 377–383. 2004.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 4

Sensory Descriptors

Geoffrey R. Nute

Contents

4.1 Introduction 49
4.2 Category Scales 51
4.3 Sensory Descriptive Profiles 54
4.4 Model Systems 57
4.5 Conclusion 58
References 59

4.1 Introduction

The science of sensory evaluation is still evolving as compared to the more established sciences of chemistry and physics. Indeed, the first textbook was written in Polish ca. 1957 by Tilgner[1] and the first textbook in English was by Amerine et al.[2] in 1965. The latter had its origins based on a review of the literature since 1940 and formed part of a course majoring in food science at the University of California, Davis, that started in 1957.

Stone and Sidel[3] defined sensory evaluation as *a scientific method used to evoke, measure, analyze and interpret those responses to products as perceived through the senses of sight, smell, touch, taste and hearing.*

An essential aspect of measuring these responses rely on the assessors who are able to accurately describe the characteristics of the stimuli that they are receiving. This leads to the need to understand and convey the characteristics of these responses to other assessors so that they understand and rate these characteristics in a similar way. This then forms the basis of the construction of either a category or an intensity scale or a present or absent rating.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

An early work by Jones and Thurstone[4] and Jones et al.[5] used a list of 51 words and phrases that could be used as anchors for hedonic scales. These words or phrases were each rated on a 9-point category scale ranging from greatest dislike (–4) to greatest like (+4) and scale values and standard deviations produced for each word or phrase.

This work showed that words with an estimated value close to the assigned physical scale and with a small standard deviation tended to be the least ambiguous and were the preferred words to be included in a scale.

A systematic approach used to select texture descriptors[6] involved the tedious job of searching the *Concise Oxford Dictionary* for texture terms and their definitions; a short list by way of illustration are "Chalky, crisp, doughy, firm, flaky, fleshy, floury, flabby, greasy, hard, juicy, lean, limp, mushy, oily, powdery, ripe, rotten, rubbery, sandy, short, sleepy, slushy, soft, springy, sticky, syrupy, tender, thick, thin, tough, treacly, viscous, watery, waxy, woody." In all, approximately 60 descriptors were listed. This highlights the vast vocabulary than can arise from trying to describe just one facet of the eating experience. A further study involved the classification of odors; Harper et al.[7] listed some 300 terms of which about 69 were then presented to consumers in a questionnaire where respondents were required to judge the usefulness of the terms to describe odor. This list was then reduced to 44, which was subsequently published as a glossary of odor qualities.[8]

Later in the mid-1970s, Szczesniak et al.[9] developed the texture profile method that was used with a fixed set of force-related attributes to describe and characterize the rheological and tactile properties of food. Assessors were trained to recognize specific points on an intensity scale and were provided with effective standards for each intensity.

A further work tracked the changes in the perception of sensory attributes during the mastication process. A work by Brown et al.[10] concluded that eating roasted meat samples and recording changes in the perception of tenderness, using time intensity methods, revealed significant correlations between the amount of masticatory muscle activity during chewing as measured by electromyography and tenderness. They ascribed the differences among assessors to the difference in the way chewing broke down the structure of the samples. Therefore, the perceived stimulus and hence their rating of a descriptor was affected by inherent differences in chewing and masticatory behavior.

A work by Nute et al.[11] on ham used 22 descriptors covering appearance, texture, and flavor, and derived a consensus configuration using generalized Procrustes analysis (GPA) and then applied principal components to integrate instrumental and chemical determinations into the consensus space. This showed that traditional hams (containing less water than in the starting material) were linked with increased tensile parameters of stiffness, shear strength, ultimate tensile stress, and the sensory texture descriptors of flakiness, cohesiveness, firmness, and with the flavor descriptor showing increased ham flavor.

A recent work by Giboreau et al.[12] centered on how sensory descriptors are defined and suggested a set of guidelines that could aid the formulation of more accurate definitions of sensory descriptors. They analyzed 100 sensory descriptors that included olfactory, tactile, gustative, and visual by applying linguistic criteria: syntactics, for example, nouns, verbs, and adjectives; and semantics, for example, metaphors, analogy, and synonymy. They suggested that the accuracy of definitions could be improved if they were focused on three areas: the product under study is related to the project where differences are related to formulations, benchmarking; the perceiving subject is involved in a consumer study where new products are being tested and preference mapping techniques applied to identify the underlying dimensions of acceptability;[13] and the assessors are involved in the wider aspects and have expert knowledge of the individual products. Interestingly, sensory analysts usually insist that while using detailed descriptive profiles the training covers the range of samples that are in the proposed experiment. The argument is that if assessors are

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

presented with samples that are outside their range of experience, they will not know how to rate the given intensity scales or may feel that they need a new descriptor.

This need to define sensory descriptors has been a topic of discussion among sensory analysts around the world and an attempt has been made to produce a vocabulary of terms (ISO 5492)[14] and terminology (ISO 1087)[15] used in sensory analysis. This approach has raised issues of translation because many of the definitions do not translate directly into other languages and with increasing globalization there is a need to standardize descriptive terms.

This chapter provides examples of the use of sensory descriptors in aspects of meat quality.

4.2 Category Scales

These scales are commonly used in animal production studies where basic sensory information is required; they have the advantage of being easy to use and understand from the assessors' viewpoint. Each category on the scale has a sensory descriptor that relates to a perceived intensity.

The concept of category scales has its origin based on the work of Jones et al.[5] This work describes a 9-point hedonic scale for liking that was originally developed at the U.S. Army Food and Container Institute (Quartermaster Corps) (Table 4.1).

These scales were subsequently adapted for and reduced to 8-point scales by removing the middle point (neither like nor dislike).

The uses and abuses of category scales in sensory measurement have been discussed by Riskey[16] who states that category ratings are affected by stimulus range, number of categories used, and the number of stimuli presented. He also makes the point that the same stimulus presented to an assessor on one day may not be rated the same on another day. His analogy is that a "warm day" in June may be quite different in an absolute sense to that in February. This raises the issue of contextual influences within a panel and should always be considered when organizing sensory panels, for example, a very tough sample in a panel followed by a tender sample will often result in the tender sample being rated higher than would normally be the case for those assessors that received the tough sample first; the

Table 4.1 Quartermaster Corps

9-Point Hedonic Scale	*Values Added after Assessment*
Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like nor dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

opposite effect will be observed in those assessors that received the tender sample first. This potential bias can be accounted for by employing methods outlined by MacFie et al.[17] who published designs to balance the effect of order of presentation and first order carryover effects.

In a study on the effects of final endpoint cooked temperature on the eating quality of pork, Wood et al.[18] used 8-point category scales to evaluate tenderness, juiciness, pork flavor, and abnormal flavor. The study used material, in a highly structured way, from the same individual pig to avoid contextual influences that could occur when using pork from different pigs. It was shown that using category scales with individual scale descriptors enabled assessors to differentiate samples in a uniform way. Scales with individual category descriptors are given in Table 4.2.

In terms of tenderness, there was a consistent result for different types of pigs as shown in Table 4.3. The results showed that as endpoint temperature increases, tenderness decreases and this is evident in commercial gilts, commercial entires and Stotfold (experimental farm) entires and gilts.

The other attributes of juiciness, flavor, and abnormal flavor also showed significant trends for each attribute. To summarize, as the endpoint temperature increases, tenderness decreases,

Table 4.2 Category Scales Used in the Study of Endpoint Temperature Effects on the Eating Quality of Pork Loin Steaks

	Tenderness	*Juiciness*	*Flavor/Abnormal Flavor*
8	Extremely tender	Extremely Juicy	Extremely strong
7	Very tender	Very juicy	Very strong
6	Moderately tender	Moderately juicy	Moderately strong
5	Slightly tender	Slightly juicy	Slightly strong
4	Slightly tough	Slightly dry	Slightly weak
3	Moderately tough	Moderately dry	Moderately weak
2	Very tough	Very dry	Very weak
1	Extremely tough	Extremely dry	Extremely weak

Table 4.3 Influence of Endpoint Cooking Temperature on the Tenderness of Pork Loin Steaks from Different Sources

	Final Internal Endpoint Temperature (°C)			
	65	*72.5*	*80*	*Significance*
Commercial gilts	5.1	4.5	4.2	***
Stotfold gilts	5.6	5.2	4.6	***
Commercial entires	5.5	4.9	4.3	***
Stotfold entires	5.7	5.2	4.8	***

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

juiciness decreases, flavor increases, and abnormal flavor decreases. At low endpoint temperatures, tenderness increases, juiciness increases, flavor decreases, and abnormal flavor increases.

The category scale approach using a standard texture description of varying degrees of toughness/tenderness and in addition local scales for texture, juiciness, and flavor were used to compare beef quality across five European countries, given sets of steaks from the same animals.[19] Eight countries supplied steaks to all participating sensory panels. The results showed a good agreement among countries for the descriptor tenderness, but flavor and juiciness were poorly related, indicating that these descriptors were not rated in the same way. However, since the range of texture was large, it tended to dominate the other sensory attributes. A later study[20] produced steaks with a smaller range of tenderness so that juiciness and flavor would not be dominated by ranges in toughness. Their results showed that tenderness and juiciness were assessed in a consistent way, but flavor was the least consistent, indicating that the descriptor beef flavor has either a different meaning or that what constitutes beef flavor has different perceptions in different countries.

A later study on lamb[21] compared the eating quality of lamb by British and Spanish taste panels, using the same basic descriptors, but treating descriptors as categories in British panels and using unstructured 100 mm line intensity scales with anchor points at each end in Spain. This was intended to explore two areas; first, whether the two panels tasting lamb from the same animals (left-side loins to Spain, right-side loins to the United Kingdom) achieved the same conclusion, indicating that the descriptors were used in the same way and second, whether the inclusion of a hedonic scale for overall appraisal was viewed in a similar way. Results showed that lamb odor intensity, tenderness, juiciness, and flavor intensity were assessed in the same way by assessors in different countries and produced similar conclusions (see Table 4.4).

However, the inclusion of the hedonic scale produced significant differences. The Spanish panel preferring Spanish lamb and the U.K. panel preferring British lamb are indicated in Table 4.5.

Table 4.4 A Comparison of Interpretation of Eating Quality Attributes of Grilled Lamb Loins between Spanish and British Taste Panels

Breed	*Spanish Merino (SM)*	*Rasa Aragonesa (RA)*	*British Export (BE)*
Lamb odor intensity			
British panel	2.83^{b}	2.69^{b}	4.03^{a}
Spanish panel	57.95^{b}	58.47^{b}	67.34^{a}
Tenderness			
British panel	6.21^{a}	5.30^{b}	6.45^{a}
Spanish panel	72.52^{a}	58.46^{b}	69.32^{a}
Juiciness			
British panel	5.18^{a}	$5.13^{a,b}$	5.05^{b}
Spanish panel	64.05^{a}	61.69^{a}	45.11^{b}

Note: Different superscripts within a row indicate significant differences between the samples.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 4.5 A Comparison of Hedonic Ratings of Eating Quality of Grilled Lamb Loins between Spanish and British Taste Panels

Breed	*SM*	*RA*	*BE*
Overall appraisal			
British panel	3.49[b,c]	3.43[c]	4.74[a]
Spanish panel	59.48[a]	57.82[a]	32.01[b]

Note: Different superscripts within a row indicate significant differences between the samples.

The categories with descriptive steps are used to establish major differences in eating quality; however, for further information and relationships between odor, texture, and flavor as perceived with information derived from chemical and instrumental measurements, more elaborate descriptors are employed.

4.3 Sensory Descriptive Profiles

Earlier, the use of category scales gave indications of the differences between lambs fed different diets; correlations between the descriptors and fatty acid composition[22] showed that lamb odor and lamb flavor were correlated with different fatty acids as shown in Table 4.6.

Lamb odor and flavor were positively correlated with oleic, EPA, and linolenic acids and negatively correlated with linoleic and arachidonic fatty acids.

On the basis of these correlations, a descriptive profile was developed to investigate variations in eating quality of lamb types from diverse production systems.[23]

This profile concentrated primarily on flavor and included the descriptors: lamb flavor intensity, abnormal flavor intensity, fatty/greasy, sweet, acidic, metallic, bitter, stale, rancid, livery, vegetable, grassy, fishy, and ammonia. Significant terms are given in Table 4.7.

Table 4.6 Sensory Analysis Descriptors Correlated with Fatty Acid Composition (mg/100 g of Muscle)

	Lamb Odor		*Lamb Flavor*	
	U.K. Lamb	*Spanish Lamb*	*U.K. Lamb*	*Spanish Lamb*
Oleic	0.59*	0.30	0.61*	0.48*
Linoleic	–0.63	–0.65	–0.69*	–0.67*
Linolenic	0.64	0.42	0.75	0.57
EPA	0.58	0.44	0.76	0.45
Arachidonic	–0.54	–0.49	–0.55	–0.54

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 4.7 Flavor Descriptors Used to Distinguish Different Lamb Types/ Production Systems

Feeding/Finishing	*Welsh Mountain Upland Flora*	*Soay Grass*	*Suffolk Grass*	*Suffolk Concentrates*
Attribute				
Lamb flavor intensity	20.5[b]	13.5[a]	27.2[c]	14.9[a]
Abnormal lamb flavor	28.8[a]	41.8[b]	28.2[a]	45.0[b]
Fatty/greasy	21.6[b]	19.0[a]	18.2[a]	19.5[a]
Sweet	12.1[c]	7.2[a]	11.2[b,c]	9.1[b]
Metallic	10.6[a]	14.3[b]	9.2[a]	11.6[a,b]
Bitter	10.9[a]	15.9[b]	10.5[a]	14.0[b]
Stale	8.9[a]	12.3[b]	8.1[a]	11.9[b]
Rancid	6.9[a]	11.0[b]	6.8[a]	10.3[b]
Livery	16.2[a]	20.5[b]	14.9[a]	16.7[a]
Fishy	2.6[a]	4.8[b]	1.4[a]	2.0[a]
Ammonia	3.1[a]	5.9[b]	2.5[a]	5.4[b]

Note: Different superscripts within a row indicate significant differences, $p < .05$, between the lamb types.

The highest ratings for lamb flavor intensity came from Welsh Mountain and Suffolk lambs reared on grass and the lowest from Suffolk lambs reared on concentrates. Although the Soay was finished on grass their flavor profile was very similar to that of the Suffolk reared on concentrates. The Soay was also very high in n-6 and n-3 PUFA that are prone to peroxidation and were probably responsible for livery flavor rated as significantly higher than in other breeds.

A later study by Nute et al.[24] on the effects of dietary oil source on lamb flavor defined each of the flavor terms in both muscle and lamb fat (see Table 4.8).

Exploring the relationship between sensory attributes and fatty acid composition showed that lamb flavor was positively correlated with conjugated linoleic acid (CLA), 18:3n-3 (α-linolenic acid) and negatively correlated with DHA 22:6n-3 (docosahexaenoic acid).

Abnormal flavor was correlated with bitter, fishy, and rancid. The former two descriptors were correlated with 18:0 (stearic acid) and the latter with CLA.

The use of these descriptors have been effective in demonstrating that when formulating diets that are perceived to improve nutritional ratios in lamb meat, there can be adverse effects on flavor and the reason for these adverse flavors can now be related to the fatty acid composition of the meat. A review by Melton[25] provided information on the role of sensory analysis in red meat flavor and a later review by Wood et al.[26] concentrated on the effects of fatty acids on meat quality and included relationships between sensory descriptions and fatty acid concentrations in meat.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 4.8 Flavor Descriptors and Definitions Used in the Assessment of Cooked Lamb Muscle

Term	*Description*
Lamb flavor	Intensity of cooked lamb flavor
Abnormal lamb flavor	Intensity of abnormal flavor
Fatty/greasy	The taste associated with oil and fat
Sweet	The taste associated with sugars
Livery	The taste associated with liver
Acidic	The taste associated with acids
Metallic	A tangy metal taste
Bitter	The taste associated with caffeine/quinine
Rancid	The taste associated with rancid, stale fat
Posset	The taste associated with the smell of warm sour milk
Fishy	The taste associated with fish
Grassy	The taste associated with vegetables/grass
Ammonia	Pungent, stale urine
Soapy	The taste associated with soap
Toughness	End points 0 (extremely tender) to 100 (extremely tough)
Juiciness	End points 0 (extremely dry) to 100 (extremely juicy) overall

Note: All terms were evaluated on 0–100 mm line intensity scales where 0 = nil intensity and 100 = extreme intensity.

Lipid oxidation is of major importance in meat quality, especially with the demands of increasing shelf life required at the point of sale. Rancidity, as a measure of oxidation, is usually measured by the concentration of thiobarbituric acid-reactive substances (TBARS) and expressed as mg of malonaldehyde per kg of lean muscle. Values ranging between 0.6 and 2.0[27] have been quoted to be responsible for oxidized beef flavor thresholds.

In a study by Campo et al.,[28] meat from 73 Angus and Charolais cross steers reared on 10 different diets including grass silage, cereal concentrate, three diets with 3% added fat and a further three diets that contained protected fish oil, a constant amount of unprotected fish oil and a control unprotected fish oil diet were used to study the relationship between TBARS and sensory attributes.

Meat from these animals were aged for 10–13 days and then displayed under retail conditions for 0, 4, or 9 days.

A set of sensory descriptors for beef flavor was developed that included the terms, beef flavor intensity, abnormal flavor intensity, rancid, greasy/oily, bloody, metallic, livery, bitter, sweet, acidic, which are defined in Table 4.9. The mean values for each of these terms were correlated with TBARS.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 4.9 Definition of Beef Sensory Descriptors Used in the Assessment of Flavor Oxidation in Beef

Term	*Description*
Beef flavor intensity	Flavor associated with cooked beef
Abnormal flavor intensity	Abnormal flavor not found in cooked beef
Rancid	Rancid flavor found in meat
Greasy	Flavor associated with oil
Bloody	Flavor associated with blood or raw beef
Metallic	Flavor associated with meat taste
Livery	Flavor associated with liver
Bitter	Bitter taste
Sweet	Sweet taste
Fishy	Flavor associated with fish
Acidic	Sour taste
Cardboard	Flavor associated with wet cardboard and stale
Vegetable	Flavor associated with vegetables
Grassy	Flavor associated with fresh grass
Dairy	Flavor associated with dairy products

Beef flavor intensity decreased as display time increased and abnormal beef flavor increased. Rancid flavor increased with display time and followed a similar pattern to abnormal flavor intensity. Rancid flavor was also highly correlated with greasy flavor.

These relationships suggested that a TBAR value of approximately 2 could be considered as the limit for acceptability of beef.

4.4 Model Systems

The use of model systems, defining how compounds are perceived, is a useful route for characterizing odors and flavors that are associated with taints. A particular problem that has plagued meat science for many years has been the elucidation of what constitutes "boar taint." The compounds responsible have been identified as skatole and androstenone. Skatole is primarily produced in the hindgut by degradation of tryptophan by microbial action. Androstenone is produced in the Leydig cells of the testes and comes under the control of gonadotropin-releasing hormones. Once synthesized, the circulating androstenone is absorbed and stored in the salivary glands or in adipose tissue where it is concentrated as a result of its lipophilic nature.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 4.10 Mean Odor Panel Ratings of Relevant Descriptors of "Boar Taint" in Pork Fat Classified According to Convention

Descriptor	*LA-LS*	*HA-LS*	*HA-HS*
Acrid	9.92[a]	14.80[b]	21.03[c]
Mothball	2.50[a]	3.80[b]	23.50[c]

Note: LA-LS = Low androstenone and low skatole; HA-LS = High and rostenone and low skatole; HA-HS = High androstenone and high skatole. Values with different superscripts, within a row, are significantly different at $p < .05$.

As far as consumers are concerned, these two compounds can result in an objectionable taint that often leads to the rejection of the meat. The problem for sensory analysts is to produce a descriptive profile that will enable identification and distinction of these two compounds.

The approach used was described by Annor-Frempong et al.[29] They used spiked vegetable fat as a model carrier with varying concentrations of androstenone and skatole, initially as a single entity and then in combination.

Androstenone odor was characterized, summary descriptions in brackets, as acrid (bitter, pungent, caustic), ammonia (pungent, stale urine), sweaty (stale sweat), parsnip (smell of cooked parsnip), silage, (fresh smell, sweet, and sickly), dirty (soiled, unclean). Skatole was defined by mothball (naphthalene), musty (stale, old fabric).

Subsequently, combinations of androstenone and skatole were presented to assessors. This showed that the perception of acrid and ammonia notes of androstenone were enhanced in the presence of skatole, whereas sweaty and parsnip notes were suppressed. The conclusion from this work on models shows that when skatole and androstenone are combined,[30] the rate of change based on skatole ratings is increased by a factor of 3, but when considering androstenone, the rate of change in intensity remains at a fairly constant level.

A later work by Annor-Frempong et al.[31] looked at the descriptions of androstenone and skatole in pork fat. Pork fats were classified according to the convention based on androstenone and skatole, that is, low androstenone (<0.5 $\mu g\ g^{-1}$), low skatole (<0.2 $\mu g\ g^{-1}$), termed LA-LS; high androstenone (>0.5 $\mu g\ g^{-1}$), low skatole (<0.2 $\mu g\ g^{-1}$), termed HA-LS; and high androstenone (>0.5 $\mu g\ g^{-1}$), high skatole (>0.2 $\mu g\ g^{-1}$) termed HA-HS.

Using the descriptive terms described earlier, assessors were able to differentiate the different classes of androstenone and skatole as shown in Table 4.10.

4.5 Conclusion

The use of sensory descriptors, by trained sensory assessors, provides an important tool in studying the components of eating quality. It is important to note that the statistical approaches used to study the ways in which assessors rate descriptors are crucial. It is vital that checks are made to measure the performance of the panel, including the methodology to check the understanding

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and meaning of descriptors and reproducibility of ratings. The works that have been described demonstrate the use of sensory descriptors in meat quality work.

They provide a synopsis of the different areas that can be studied using sensory descriptors; the examples are by no means exhaustive but cover the current areas of interest.

References

1. Tilgner, D.J. Analiza organoleptyczna zywnosci. Warszawa: Wydawnictwo przemyslu Lekkiego I Spozywczego. 1957.
2. Amerine, M.A., Pangborn, R.M., and Roessler, E.B. *Principles of Sensory Evaluation of Food*. Academic Press, New York, 1965.
3. Stone, H. and Sidel, J.L. *Sensory Evaluation Practices*, 2nd ed. Academic Press, San Diego, USA, 1993.
4. Jones, L.V. and Thurstone, L.L. The psychophysics of semantics: an experimental investigation. *J. Appl. Psychol*., 39: 31–36, 1955.
5. Jones, L.V., Peryam, D.R., and Thurstone, L.L. Development of a scale for measuring soldier's food preferences. *Food Res*., 20: 512–520, 1955.
6. Harper, R. Texture and consistency from the standpoint of perception: some major issues. In: *Rheology and Texture in Foodstuffs*. Monograph No. 27, Society of Chemical Industry, London, 11–28, 1968.
7. Harper, R., Bate-Smith, E.C., and Land, D.G. *Odour Description and Odour Classification*. Churchill, London, 1968.
8. Harper, R., Land, D.G., Griffiths, N.M., and Bate-Smith, E.C. Odour qualities: a glossary of usage. *Br. J. Psychol*., 59: 231–252, 1968.
9. Szczesniak, A.S., Loew, B.J., and Skinner, E.Z. Consumer texture profile technique. *J. Food Sci*., 40: 1253–1257, 1975.
10. Brown, W.E., Langley, K.R., Mioche, L., Marie, S., Gerault, S., and Braxton, B. Individuality of understanding and assessment of sensory attributes of foods, in particular, tenderness of meat. *Food Qual. Pref*., 3/4: 205–216, 1996.
11. Nute, G.R., Jones, R.C.D., Dransfield, E., and Whelehan, O.P. Sensory characteristics of ham and their relationships with composition, visco-elasticity and strength. *Int. J. Food Sci. Technol.,* 22: 461–476, 1987.
12. Giboreau, A., Dacremont, C., Egoroff, C., Guerrand, S., Urdapilleta, I., Candel, D., and Dubois, D. Defining sensory descriptors: towards writing guidelines based on terminology. *Food Qual. Pref.,* 18: 265–274, 2007.
13. Nute, G.R., MacFie, H.J.H., and Greenhoff, K. Practical application of preference mapping. In: *Food Acceptability*, eds. Thomson, D.M.H. Elsevier Applied Science, London, UK, 377–386, 1988.
14. ISO (1992). Sensory analysis—Vocabulary. ISO 5492. International Organisation for Standardisation, Geneva.
15. ISO (1990). Terminology—Vocabulary. ISO 1087. International Organisation for Standardisation, Geneva.
16. Riskey, D.R. Use and abuses of category scales in sensory measurement. *J. Sensory Studies*, 3/4: 217–236, 1986.
17. MacFie, H.J., Bratchell, N., Greenhoff, K., and Vallis, L.V. Designs to balance the effect of order of presentation and first-order carry-over effects in hall tests. *J. Sensory Studies*, 4: 129–148, 1989.
18. Wood, J.D., Nute, G.R., Fursey. G.A.J., and Cuthbertson, A. The effect of cooking conditions on the eating quality of pork. *Meat Sci.,* 40: 127–135, 1995.
19. Dransfield, E., Rhodes, D.N., Nute, G.R., Roberts, T.A., Boccard, R., Touraille, C., Butcher, L., Hood, D.E., Joseph, R.L., Schon, I., Casteels, M., Cosentino, E., and Tinbergen, B.J. Eating quality of European beef assessed at five research institutes. *Meat Sci.,* 6: 163–184, 1982.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

20. Dransfield, E., Nute, G.R., Roberts, T.A., Boccard, R., Touraille, C., Butcher, L., Casteels, M., Cosentino, E. Hood, D.E., Joseph, R.L., Schon, I., and Paardekooper, E.J.C. Beef quality assessed at European research centres. *Meat Sci.,* 10: 1–20, 1984.
21. Sanudo, C., Nute, G.R., Campo, M.M., Maria, G., Baker, A., Sierra, I., Enser, M., and Wood, J.D. Assessment of commercial lamb meat quality by British and Spanish taste panels. *Meat Sci.,* 1/2: 91–100, 1998.
22. Sanudo, C., Enser, M.E., Campo, M.M., Nute, G.R., Maria, G., Sierra, I., and Wood, J.D. Fatty acid composition and sensory characteristics of lamb carcasses from Britain and Spain. *Meat Sci.,* 54: 339–346, 2000.
23. Fisher, A.V., Enser, M.E., Richardson, R.I., Wood, J.D., Nute, G.R., Kurt, E., Sinclair, L.A., and Wilkinson, R.G. Fatty acid composition and eating quality of lamb types derived from four diverse breed x production systems. *Meat Sci.*, 55: 141–147, 2000.
24. Nute, G.R., Richardson, R.I., Wood, J.D., Hughes, S.I., Wilkinson, R.G., Cooper, S.L., and Sinclair, L.A. Effect of dietary oil source on the flavour and the colour and lipid stability of lamb meat. *Meat Sci.,* 77: 547–555, 2007.
25. Melton, S.L. Effects of feeds on flavour of red meat: a review. *J. Anim. Sci.,* 68: 4421–4435, 1990.
26. Wood, J.D., Richardson, R.I., Nute, G.R., Fisher, A.V., Campo, M.M., Kasapidou, E., Sheard, P.R., and Enser, M. Effects of fatty acids on meat quality: a review. *Meat Sci.,* 66: 21–32, 2003.
27. Greene, B.E. and Cumuze, T.H. Relationship between TBA numbers and inexperienced panellists' assessment of oxidised flavour in cooked beef. *J. Food Sci.,* 47: 52–54, 58, 1994.
28. Campo, M.M., Nute, G.R., Hughes, S.I., Enser, M., Wood, J.D., and Richardson, R.I. Flavour perception of oxidation in beef. *Meat Sci.,* 72: 303–311, 2006.
29. Annor-Frempong, I.E., Nute, G.R., Whittington, F.W., and Wood, J.D. The problem of taint in pork: 1. Detection thresholds and odour profiles of androstenone and skatole in a model system. *Meat Sci.,* 46: 45–55, 1997.
30. Annor-Frempong, I.E., Nute, G.R., Whittington, F.W., and Wood, J.D. The problem of taint in pork: 2. The influence of skatole, androstenone and indole, presented individually and in combination in a model lipid base, on odour perception. *Meat Sci.*, 47: 49–61, 1997.
31. Annor-Frempong, I.E., Nute, G.R., Whittington, F.W., and Wood, J.D. The problem of taint in pork:3. Odour profile of pork fat and the interrelationships between androstenone, skatole and indole concentrations. *Meat Sci.,* 47: 63–76, 1997.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 5

Sensory Perception

Rosires Deliza and Maria Beatriz Abreu Glória

Contents

5.1 Introduction 62
5.2 Factors Affecting Quality Perception 63
5.2.1 Consumer Expectations 64
5.3 Sensory Evaluation and Consumer Studies 67
5.3.1 Methods Used in Sensory Evaluation 70
5.3.1.1 Discriminative Tests 70
5.3.1.2 Descriptive Tests 70
5.3.1.3 Affective Tests 71
5.4 Factors Affecting the Sensory Quality of Meat 75
5.4.1 Type of Meat 75
5.4.1.1 Chicken Meat 75
5.4.1.2 Pork Meat 76
5.4.1.3 Beef Meat 76
5.4.1.4 Goat Meat 77
5.4.2 Genetic Factors 77
5.4.3 Warmed-Over Flavor 78
5.4.4 Production and Rearing Conditions 78
5.4.5 Effect of Postmortem Practices, Product Preparation, and Ingredients on Meat Quality 80
5.5 Influence of the Improvement of Nutritional Value on Sensory Quality 81
5.6 Concluding Remarks 81
Abbreviations 82
References 82

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

5.1 Introduction

The sensory quality of meat and meat products has been considered an important factor since the beginning of the food industrialization process due to its influence on the overall quality of the product. Quality, in terms of sensory properties, is related to the adequate levels of sensory attributes considering the appearance, aroma, flavor, and texture. The sensory quality of a product has to be considered under several perspectives, mainly if it takes into account the consumer point of view. It is known that consumers create subjective impressions about the quality of a product based on various psychological processes. These processes are influenced by many factors such as the previous knowledge and cognitive competencies of each individual consumer [1]. Thus, from a consumer perspective, quality refers to the perceived quality and not to quality in an objective way.

Several approaches have been used to study the perception process of food quality by consumers. Within the widely accepted multiattribute approach, quality is a multidimensional phenomenon, described by a set of characteristics (attributes) that are subjectively perceived by consumers [2,3]. Perceived quality is generally considered as an overall concept and can be defined and analyzed, according to Oude Ophuis and Van Trijp [4], as the four "Ps" of the quality quadrant (Figure 5.1).

The first P in the perceived quality refers to the *Perception* process, which is related to the overall judgment formed on the basis of visible and invisible product characteristics that may have been experienced, or are believed to be associated with the evaluated product. Perceived quality may differ depending on the *Product* or product category under investigation (second P). Fat content, for example, may be a quality attribute (positive or negative) for meats, but it can have no relevance for fruits and vegetables. This leads to the consideration that perceived quality is based on consumer's judgments, the *Person* factor (third P), suggesting that perceived quality would vary among people, as they differ in their perceptual abilities, personal preferences, lifestyles, and experiences [5]. The fourth P of the quadrant is related to the context, and referred to as *Place*. There are many situations or circumstances that affect perceived quality, such as availability, price, social facilitation, and appropriateness of the eating environment (e.g., pizza may be judged as an excellent food to be consumed in evening meals, but inadequate for breakfast). Bell and Meilselman [6] have

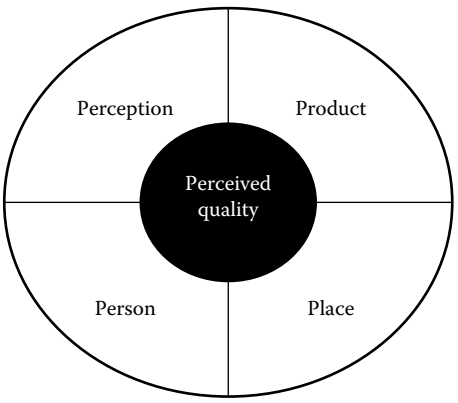


Figure 5.1 The quality quadrant. (From Oude Ophuis, P.A.M. and Van Trijp, H.C.M., *Food Qual. Prefer.*, 6, 177, 1995. With permission.)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

taken into account these factors when investigating the role of eating environments in determining food choice.

In this chapter, the perceived quality of meat and meat products will be considered, taking into account intrinsic and extrinsic quality cues, and their effects on consumer judgment regarding the products and consumer's food choice. The perceived quality of the product is multidimensional and includes sensory quality, healthiness, convenience, and for some consumers, product characteristics like animal welfare and organic production. The difference between intrinsic and extrinsic quality cues are presented and discussed in a wide scenario.

5.2 Factors Affecting Quality Perception

Food products are developed, produced, and marketed to appeal to the consumer, who is becoming more and more demanding about quality. The perception of food quality, particularly meat, is changing rapidly [7], which highlights the need for food producers to be innovative as a way to survive [5]. In other words, the success of a product depends on its acceptance by consumers, because they are the ultimate users of the product and thus, the ones who will be willing to purchase the product. Therefore, professionals in various industries are eager to understand consumer perceptions and attitudes toward a new product, a formulation change, or a new process. If a product is not liked by consumers, the research or manufacturing project is considered to be a failure [8].

The sensory attributes of food products can be either intrinsic or extrinsic (Table 5.1). Intrinsic attributes are concrete product characteristics that can be perceived by a consumer and, in many situations, can serve as a quality cue that can be observed, without actual consumption or use. It is related to the appearance, color, shape, size, and structure, all of them extremely important for meat. Intrinsic attributes are always related to the physical aspects of the product.

Extrinsic quality cues refer to product characteristics that are used to evaluate a product but are not physically part of it, such as price, brand, production and nutritional information,

Table 5.1 Intrinsic and Extrinsic Sensory Attributes of Food Products

Intrinsic	*Extrinsic*
Appearance	Price
Color	Brand name and familiarity
Shape	Label (packaging design)
Size	Advertisement
Structure	Nutritional information
Aroma	Production information (environment, organic)
	Origin (country)
	Store name
	Convenience

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

packaging design, country of origin, store, and convenience (Table 5.1). Extrinsic cues become more important when products are very similar in appearance [4]. The intrinsic and extrinsic cues are categorized and integrated by consumers to establish the quality attributes of meat.

According to Steenkamp [9], quality attributes can also be *experience* or *credence cues*. The experience originates from the actual experience with or consumption of the product (e.g., aroma, taste, tenderness, leanness, etc.), whereas credence cannot be ascertained even after normal use (buying and consuming the product). Examples of credence cues are hormones, bovine spongiform encephalopathy (BSE), animal welfare, animal feeding, among others. These cues are gaining importance due to the increased consumer's concerns on safety, health, convenience, and ethical factors, in particular for meat and meat products.

In a study carried out by Bernués et al. [2], approximately 80% of the participants considered animal feeding and origin of meat, followed by animal welfare and environmentally friendly production, as the most appreciated extrinsic attributes of beef and lamb. Under the multiattribute approach, *experience* and *credence* quality are integrated by the consumer into an overall perceived quality, making the process very dynamic.

5.2.1 Consumer Expectations

Although sensory properties are by far the most important quality dimensions driving consumer's food choices, extrinsic product factors such as brand, price, and information can also affect food choice. Information given through the label of the package can be used to create positive expectation aimed to modify consumer perception and enhance purchase intention. During the decision-making process, previous experience and all the information available are processed in the consumer's mind.

Expectation is defined as the "action of mentally looking for something" in the food product to come. It plays an important role because it may improve or degrade the perception of a product, even before it is tasted. The higher the expectation levels about the product, the greater chances it has of being purchased. However, low expectation can cause the product to be ignored [10–13]. After making a choice, the consumer tastes the product, appreciating its sensory properties and other features that have created the expectation. Once confirmed, the consumer is pleased and possibly purchases the product again in a future experience. It means that the effects of expectation are likely to be important variables in determining satisfaction with the product [14]. A common hypothesis is that satisfaction is achieved when the product meets the consumer's expectation [15,16]. The ability to determine such expectation about a particular product becomes a vital strategy in promoting consumer's sensory satisfaction.

A model summarizing the role of expectations in product selection and evaluation is shown in Figure 5.2. As it can be seen, if disconfirmation of the expectation occurs, a mismatch between the expected and the actual product evaluation will occur. If the expectation is low and the sensory quality of the product is high, there will be a positive disconfirmation, and hence, consumer satisfaction is achieved. Conversely, high expectation on a poor sensory quality product will lead to a negative disconfirmation. In both cases, depending on the individual's behavior, the evaluation can be driven either toward or opposite to the initial expectation level [10,17].

There are two main models to explain the influence of information on food acceptance: assimilation and contrast [10]. Assimilation is the most described model and seems to come up mostly in cases of higher expectation and lower sensory quality. The individual tastes the product and receives information about it. Both dimensions—sensory and information—are integrated in his mind. If the product is perceived as worse than expected, cognitive dissonance takes place and to

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

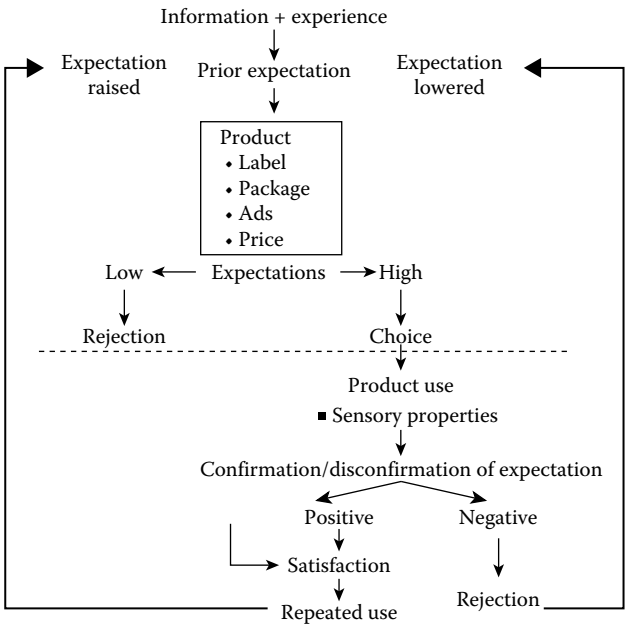


Figure 5.2 Model illustrating the influence of expectation on product selection and evaluation. (From Deliza, R. and MacFie, H.J.H., *J. Sens. Stud.*, 11, 103, 1996. With permission.)

overcome it, the judgment moves toward expectation [13,17,18]. The second model—contrast—can be observed when sensory quality plays the most important role. The individual has high expectation; hence he evaluates the product and dislikes it. Therefore, the product is perceived as worse than expected. This is called a negative contrast. However, a product perceived as good but with a low expectation level tends to be well accepted—a positive contrast [12].

Two other models are cited in the literature: generalized negativity and assimilation–contrast. In the first case, when the consumer has a different perception from the expected, it will be rated worse than if there had been no expectation. Assimilation–contrast, however, is related to the size of the discrepancy between expected and actual product performance. When the perceived discrepancy is small, the person tends to ignore it and there will be assimilation. Large discrepancies are not acceptable and contrast will occur [19].

To develop expectations about the products, consumers use intrinsic and extrinsic cues. Several factors affect the perception of meat quality such as the increased consumer health concerns, change in demographics, the need for convenience, changes in the distribution of meat, and price. Table 5.2 summarizes this issue considering the European consumer, emphasizing the meat industry's need for understanding the consumers and the measurement methods used to assess their attitudes and preferences [20].

In a study carried out on beef by Grunert et al. [21] in four European countries, the major cues used by consumers to elaborate quality expectations and the major dimension of meat quality were identified. Two factors formed the basis of quality expectations: perceived fat and place of purchase. The consumers had difficulty in evaluating meat quality, resulting in uncertainty and dissatisfaction. However, several possibilities were envisioned in the development of differentiated products, including improvement of eating quality, positive health effects, added convenience, and desirable

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 5.2 European Consumer Expectations about Food of Animal Origin

Hygiene
Safety
Freshness
Nutritional value
Clear labeling
Ingredients
Price
Packaging
Brand reputation
Convenience
Product consistence
Suitability for specific situation
Origin
Ethical aspects
Environmental considerations
Appearance and sensory characteristics (flavor, color, aroma, etc.)

Source: ECA, www.esn-network.com/683.htwml, 1999; Ressurreccion, A.V.A., *Meat Sci.*, 66, 11, 2004. With permission.

process characteristics. The authors pointed out that product development is difficult and risky, and emphasized the need of consumer-led product development for the successful development of new products.

In a recent study [5], three main trends were identified on the role of meat in the life of consumers, using the food-related lifestyle model as a conceptual framework. First, the increasing influence of extrinsic cues on quality perception of meat poses new requirements for the organization of the meat value chain, which has to fulfill the functions of delivering both meat and information. The second trend relates to the distinction of fast and efficient shopping in supermarkets compared to buying information-intensive specialized products from specific retail outlets. Although the bulk of meat will still be bought in supermarkets, in the future, there may also be room for other retail channels for specialized products. And finally, there is an increasing role of processed products, due to both convenience and trends toward meat avoidance in some consumer groups. Convenience is one of the major trends in food, whereas meat avoidance is a trend restricted to certain consumer groups; but both can lead to similar implications: making available

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

products with a higher degree of processing, which enables more built-in convenience and less visibility of the meat ingredient, leads to a movement from bulk to differentiated, value-added products, which is probably the greatest trend of all.

Traditionally, quality perception of meat has been largely based on intrinsic cues such as color of the meat, the visible fat, and the cut. This is not mainly because consumers have been very competent in inferring quality from these cues, but because fresh meat is an unbranded product and only few extrinsic cues are available [5]. Focusing on intrinsic product characteristics, a huge diversity of analyses can be carried out to evaluate, control, and estimate product quality, either at a specific time, or during the product shelf life. A product can be evaluated in terms of its microbiological, chemical, or sensory characteristics; sensory cues fall under the domain of sensory evaluation, which has been defined as a scientific discipline used to evoke, measure, analyze, and interpret reactions to those characteristics of food as they are perceived by the senses of sight, smell, taste, touch, and hearing [22]. Owing to its relevance to the product evaluation, it is considered separately.

5.3 Sensory Evaluation and Consumer Studies

As mentioned earlier, the factors that affect food choice and intake are multidimensional and complex, but there is no doubt that the physical and sensory properties of a food must be among the main determinants. Therefore, it is very important that the methods used to measure the properties are accurate, not biased, and take into account the special requirements involved when humans are used as scientific measuring instruments [23]. During sensory evaluation, besides the sensory properties of the food, the responses from the sensory professional (individual providing the connection between the internal world of technology and product development and the external world of marketplace) are also analyzed and interpreted. This is done within the constraints of a product marketing brief, in a way that specialists can anticipate the impact of product changes in the marketplace [24].

The importance of sensory evaluation in the food area and, consequently, in the meat sector, is very well recognized and considered a cost-effective tool. It has its own challenges and should be viewed in broad terms. Its contribution far exceeds questions such as which flavor is best or whether ingredient X can be replaced with ingredient Z. This concept is especially important when looking at the impact of consumer response behavior as developed by marketing research.

Several studies on the physiological and psychological approaches used in the measurement of consumer behavior have been presented in the literature. Although research on sensory evaluation has only improved in recent years, there has been much information available on the physiology of the senses and the behavioral aspects of the perceptual process [24]. Comprehension of how sensory information is processed and integrated is important in understanding the evaluation process [25].

Sensory evaluation can be used for several purposes in a company. In Table 5.3, there is a list of activities to which sensory evaluation can contribute, directly or indirectly [24]. Every activity is important to the company, and the involvement of these activities will depend on the kind of company, as well as on the purpose of the study. For some companies the emphasis may be on the marketplace, new products, cost reduction and reformulation, line extension, and so on. For others, quality control is the primary focus.

In most companies sensory resources are located within the research and development area; however, it is sometimes part of the marketing research group. It depends on the company and the relationship with the involved areas. There is no rule stipulating where sensory evaluation has to be

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 5.3 Sensory Evaluation Activities Within a Company

Product development
Product reformulation and cost reduction
Monitoring competition
Quality control
Quality assurance
Product sensory specification
Raw material specification
Storage stability
Process/ingredient/analytical/sensory relationship
Advertising claims

Source: Stone, H. and Sidel, J.L., in *Sensory Evaluation Practices*, Academic Press, San Diego, CA, 2004, 377. With permission.

placed, but since most sensory professionals have some technical training and most often provide services to technical groups, sensory resources are frequently placed within the technical division. Regardless of the company goals and the location of the sensory resources, it is important to consider where the test will take place, who will serve as subjects, and which methods will be used. The accurate establishment of all mentioned factors is crucial to the achievement of the desired results [24]. The steps involved in the sensory evaluation process are presented in Figure 5.3.

An adequate planning involving the sensory analyst and the requester/client is essential. The aim of the study should be clear to the sensory analyst, that is, what is the purpose of the test, how many products will be evaluated, how the products will be prepared, and when the results are needed. In the next step, the test should be organized to guarantee that everything that is needed is available at the right time. Finally, the test is implemented, the data are collected and analyzed, and a written report is prepared, which is given to the requester in the form of recommended actions.

Physical and chemical properties are measured by instruments, whereas sensory properties are measured by a sensory panel. The panel consists of individuals selected on the basis of sensory acuity and ability to articulate the sensations experienced while viewing, smelling, and eating or drinking the food. Individuals are trained to describe products in terms of sensory characteristics and perceived product attributes' intensity. A trained panel is used for discriminative and descriptive tests. Preference and acceptability are determined by consumers, who are the users or potential users of the product.

Before presenting the methods available in sensory evaluation, it is important to make some comments about the place where the tests are carried out—the Sensory Laboratory—including the sensory booth, and other facilities. The test area should be of easy access for the people involved. A place in which most panel members pass on their way to lunch or to a break is a good location. If the panel members are coming from outside, the laboratory should be near the building entrance. Test rooms should not have noise and sources of odor, as they can affect the senses of the panel.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

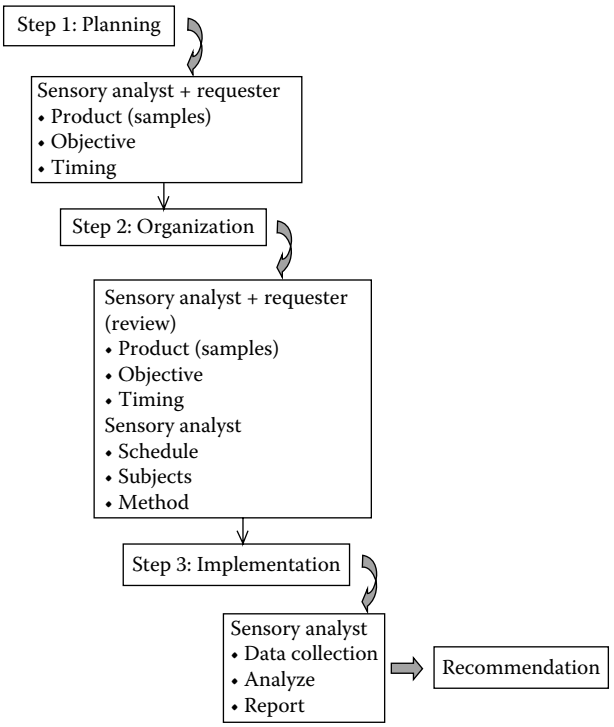


Figure 5.3 The representation of the steps involved in the sensory evaluation process. (Adapted from Stone, H. and Sidel, J.L., *Sensory Evaluation Practices*, Academic Press, San Diego, CA, 2004.)

The size of the booth, as well as the illumination, ventilation system, sinks, and temperature, should be adequate. The number of booths depends on the number and type of tests, which can be estimated before the planning of the laboratory. The booths should be individual and adjacent to the product preparation area so that samples can be served efficiently. A preparation area must contain at least refrigeration and storage facilities for ingredients and samples, cooking facility (electric or gas burners; conventional, convection, or microwave ovens), hoods with charcoal filters or venting to the outside, dishwasher, garbage disposers, waste basket, sink, and water sources. Other devices are specially used considering meat and meat products, such as heating trays, meat cutters, scales, and mixers. Another important area in the laboratory is the training area, designed to carry on training sessions with the panel. The desired characteristics of this area are as follows:

1. It should be close to the preparation area.
2. It should have a round or rectangular table (big enough for 6–12 panelists).
3. It should have controlled illumination and ventilation (similar to booth area).
4. It should be furnished with neutral color.
5. It should be nonodorous, and easy to clean.

More details about the facilities can be found in Stone and Sidel [24], American Society for Testing and Material (ASTM) [26], and Meilgaard et al. [27].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The preparation and presentation of the samples also have to be taken into account. Preliminary work is necessary before testing to determine the method of sample preparation, thawing and preparation times, equipment, and utensil. The sample should be representative or typical of the product to be tested. Proper sampling of the meat muscle is of critical importance. Every sample has to be tested at a given time and series. The experiments should be planned and performed using similar procedures, except for the factor under study.

Sample preparation guidelines for meat testing are available, wherein aspects such as thickness of steak and chops, size and thickness of roasts (beef, pork, and lamb), and meat cooking methods (roasting, broiling, and braising) are considered [28]. The order of presentation of samples has to follow a design [29], and a warmed-up sample should be used when required [30]. The serving temperature can be a cause of concern. Therefore, it has to be well controlled throughout the entire test. Generally, it is best to use the temperature at which it is usually consumed. However, in difference or descriptive tests, the temperature may be modified because taste acuity or perception is highest at temperatures between 20 and 40°C. It is recommended to provide a liquid (mineral water at room temperature) to rinse the mouth between samples. When tasting fatty foods, it is better to use warm water, dilute warm tea, lemon water, or a slice of apple. Crackers are used to remove residual flavors. The time of the test should also be relevant. If it is too early, it is difficult to evaluate hot spicy foods; however, if it is too late there is lack of motivation.

Motivation is an issue of concern to all sensory professionals, who need to develop a variety of practices to maintain the panel's interest in every study. Several recommendations were given by Stone and Sidel [24] as useful guidelines on motivation: subjects should be rewarded for participating, not for making correct scores; subjects' participation should be acknowledged on a regular basis, directly and indirectly; and management should visibly recognize sensory evaluation as a contributor to the company's growth and an indirect source of motivation.

5.3.1 Methods Used in Sensory Evaluation

5.3.1.1 Discriminative Tests

Focusing first on discriminative methods (a class of tests used to investigate whether there is a sensory difference between samples), a variety of specific methods can be found. The most common are the triangle test, duo-trio test, and paired comparison test. Triangle and duo-trio tests are used when the objective is to determine whether a sensory difference exists between two products. Paired comparison test is used to determine in which way a particular sensory characteristic differs between two samples (e.g., more or less tender). The importance of individuals' selection for a discriminative test has been known for a long time. Using unqualified people results in substantial variability that will mask a difference, leading to a wrong decision [24].

5.3.1.2 Descriptive Tests

Descriptive sensory tests are among the most sophisticated tools available to the sensory professional and involve the detection and description of both qualitative and quantitative sensory components of a product by trained panels. A relevant point of a descriptive test is its ability to allow the establishment of relationships between descriptive sensory and instrumental or consumer preference measurements. They can also be used to investigate product changes during its shelf life, and to investigate the effects of ingredients or processing variables on the final sensory properties of a product [31].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

There are several different methods of descriptive analysis, such as Flavor Profile®, Texture Profile®, Quantitative Descriptive Analysis (QDA™), the Spectrum™, and Free-choice Profiling [32]. All of them require a panel with some degree of training and, in most of them (except for Free-choice Profiling), panelists are also required to have a reasonable level of sensory acuity. The selection and training of the panel and the monitoring of the performance of individuals are discussed in several publications [24,27,31]. The tests begin with the development of the descriptive terms, which describe the attributes of the product in a comprehensive and accurate way. It is achieved by exposing individuals to a wide range of products in the category under test. A consensus list of attributes is generated by the panelists (except for Free-choice Profiling, in which each panelist has his/her own list of attributes), which is used to evaluate samples. More details on descriptive tests can be gathered from Murray et al. [31].

Descriptive analysis has been extensively used in the meat industry and there are many studies published in the area [33–35]. They vary from studies evaluating a limited number of attributes to others with a well-trained panel, following careful preparation and presentation of the samples and developing and using a technically sound lexicon to describe the sensory characteristics of meats. Table 5.4 shows examples of flavor and texture lexicon for some types of meat.

The importance of establishing correlation between descriptive sensory tests and instrumental data or consumer preference measurements was illustrated by Boleman et al. [36] and Miller et al. [37], during analysis of meat and meat products for tenderness, which is considered one of the most important qualitative characteristic of meat. According to their studies, the consumers are willing to pay a higher price for beef in the marketplace as long as it is guaranteed to be tender. However, tenderness was a highly variable characteristic, depending on many intrinsic and extrinsic factors of the animal and on their interaction. Therefore, an instrumental means of evaluating tenderness that correlates with sensory perception would be desirable to overcome the practical problem of sensory evaluation. Destefanis et al. [38] investigated the ability of consumers to discern different levels of beef tenderness established by Warner–Bratzler shear force. The results indicated that beef with Warner–Bratzler shear force higher than 52.68 N and lower than 42.87 N were perceived by most consumers as tough and tender, respectively. Therefore, these values can represent reliable thresholds to classify beef tenderness. These values were within those obtained when a trained panel was used—42.28–58.76 N, corresponding to 4.31–5.99 kg [37].

5.3.1.3 Affective Tests

The last type of sensory test described is the affective test, which has the primary objective to assess the personal response (preference and acceptance) from users or potential users of a product or product idea. It is a valuable and important component of every sensory program and is referred to as acceptance, preference, or consumer testing. Subjects taking part in a sensory acceptance test are recruited based on demographic and usage criteria, and the number of participants in the test is an important issue in the design of the study. A large number of individuals are required; however, the number recommended in the literature varies, and about 100 consumers are usually considered adequate. In a recent study, Hough et al. [39] indicated that 112 consumers were necessary to perform a test with confidence.

Acceptance testing means the measurement of liking or preference for a product. Preference can be measured directly by comparing two or more products with each other, that is, which one of the two, three, or more products is preferred. It can also be measured indirectly, by determining which product is scored higher (more liked) than another product in a multiproduct test. By using appropriate scales it is possible to directly measure the degree of liking and to compare preference

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 5.4 Flavor and Texture Lexicons for Some Types of Meat

	Beef	*Chicken*
Flavor		
Aromatics	Cooked beef/brothy	Chickeny
	Cooked beef fat	White chicken meat
	Browned	Dark chicken meat
	Liver/organy	Fat/skin
	Serum/bloody	Browned
	Grainy	Liver/organy
	Cardboard	Serum/bloody
	Painty	Cardboard
		Painty
Basic tastes	Sweetness	Sweetness
	Saltiness	Saltiness
	Sourness	Sourness
	Bitterness	Bitterness
Feeling factors	Metallic	Metallic
Texture		
Surface properties	Oiliness/wetness	Oiliness/wetness
	Roughness	Roughness
Partial compression	Springiness	Springiness
First bite	Firmness/hardness	Firmness/hardness
	Cohesiveness	Cohesiveness
	Juiciness/moisture release	Juiciness/moisture release
	Uniformity of bite	
Chew down	Cohesiveness of the mass	Cohesiveness of the mass
	Uniformity of the mass	Uniformity of the mass
	Juiciness	Juiciness
	Gristle	Gristle
	Connective tissue	

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 5.4 (continued) Flavor and Texture Lexicons for Some Types of Meat

	Beef	*Chicken*
Residual	Toothpack	Toothpack
	Number of particles	Number of particles
	Oiliness/greasiness	Oiliness/greasiness

Source: Muñoz, A.M., *Meat Sci.*, 1, S287, 1998. With permission.

from these data. The two most used methods to measure preference and acceptance are the paired comparison and the 9-point hedonic scale tests. The paired comparison test is similar to the one described in the discrimination test, but in the present situation, the consumer will indicate which one of the two coded samples is preferred. The 9-point hedonic scale is probably the most useful. Despite some criticism about such scale, it is still the most used one for preference [24].

Similar to what was mentioned for descriptive and discriminative tests, attention has to be paid concerning sample preparation and sample presentation order when acceptance test is carried out. More details about the affective testing are provided by Stone and Sidel [24]. After collecting the data, it is necessary to analyze them to get the results, and enable the researcher to prepare a report, with recommendations and further actions. A classical statistical method to analyze preference data is analysis of variance. However, a mean of sample preference is obtained, which does not take into account the individual's preference. Advanced statistical methods have been successfully used to sort this problem out, such as preference mapping [40] and cluster analysis. Preference mapping has the advantage of identifying the sensory attributes that drive consumer preference, and cluster analysis identifies segments of consumers with similar preference, allowing the elaboration of marketing strategies. As an example of the usefulness of preference mapping, there is a study examining the sources of variation in restructured steaks, which indicated that the variations in fat and salt content were the most important determinants of consumer acceptability [23,41].

Consumer research and descriptive analysis play, by themselves, important roles in meat evaluation. Consumer research gives information on consumer perception and acceptance that only consumers can provide. However, consumers, because of their lack of training and limited vocabulary, cannot provide extensive product information. A descriptive panel, however, provides accurate and detailed product description. Therefore, to obtain the complete product information, both consumer and descriptive analysis should be used [40].

The main applications of consumer-descriptive studies are to achieve more thorough interpretation and understanding of consumer responses, to provide more specific product guidance, to enable the prediction of consumer responses based on descriptive and instrumental data, and to study different consumer segments [8]. This application was demonstrated on a hot dog study by Muñoz and Chambers [34]. A product highly accepted by consumers needed to have high intensity of smoke, cured meat, sweet and fat aroma, sweetness, saltiness, moisture release, cohesiveness of the mass, residual oiliness, and also low intensity of skin awareness, firmness of the skin, grain aromatic, poultry, green herbs, pepper, onion, garlic, and speckles. Such a detailed guidance on how to formulate or reformulate this product would not have been obtained from consumers, in which the only attributes that could be asked for were color, size, hot dog flavor, spiciness, firmness, skin awareness, greasy/oily, spicy, smoky, and salty.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Consumer studies can be carried out through qualitative and quantitative studies. Qualitative studies involve the study of factors that motivate consumer opinions and behaviors. Consumer attitudes, perceptions, and beliefs that may explain the reasons for people's choices are explored. Qualitative research has an exceptional value, since the consumer can be probed to obtain information not easily obtained in quantitative studies. Consumers either participate in a group discussion (6–10 consumers) or are interviewed on an individual basis. Because of the nature of qualitative research, there are several sensory issues that may be addressed in meat studies (Table 5.5). The qualitative information can be the most important data that a researcher needs to collect and cannot be easily measured through a written questionnaire. The qualitative studies do not replace quantitative ones, but complement them [8].

Quantitative studies, however, are geared to collect data that can be summarized and analyzed statistically. The main characteristics of quantitative studies are also indicated in Table 5.5. Ultimately, researchers need this type of information and the power of statistics to make product

Table 5.5 Examples of Sensory Issues Investigated in Qualitative and Quantitative Studies of Meats

Sensory issues in qualitative studies
What did you specifically like and dislike about the product?
How did you cook this meat product?
Please explain why this color of meat is more appealing than the other color
Please explain why this steak looks greasy to you
Please tell me more about why this amount of visible fat is unacceptable to you
Why in your opinion meat product 783 is tenderer than product 245?
Why your family preferred this meat product over the others?
Sensory issues in quantitative studies
The potential user of the meat product participates
A relatively large group of consumers participates (depending on the statistical power required)
Careful consideration to the meat product amount, consistency, and preparation for the large number of participants
Written questionnaire with attributes and scales to collect the perceived levels of sensory attributes by consumers
Sensory questions may include overall liking, liking and perceived intensity of attributes and preference
The selection of attributes in the questionnaire is critical
Data are statistically analyzed

Source: Muñoz, A.M., *Meat Sci.*, 1, S287, 1998. With permission.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

decisions. However, if the quantitative research is conducted in conjunction with qualitative studies, more complete information on consumer responses is obtained [8].

Another challenge is the questionnaire design and the attributes selected to be evaluated. The attributes have to be carefully selected so that the consumers can provide meaningful information. The terms used should be consumer terms and not a technical product lexicon. The attributes also depend on the type of meat product and the variables being studied. They have to be sufficient to provide all the information needed on the meat product [42].

The consumers included in the study must be selected according to the purpose of the research because there are considerable differences between young and elderly individuals on sensory perception and pleasantness of food flavors. Furthermore, there are changes with age in functions relating concentration with perceived intensity (psychophysical), concentration with pleasantness, and perceived intensity with pleasantness, which were specific for the different flavor qualities. These observations were confirmed in a study designed to determine the perceived intensity and pleasantness of bouillon flavor in water by a group of 32 young (mean age: 22, range 20–25) and 23 elderly individuals (mean age: 76, range 72–82). On average, the elderly subjects had lower perceived intensities for the highest concentrations of the series of bouillon, whereas the average responses to the lowest concentrations were almost equal. Optimal preferred concentrations were higher for the elderly than for the young subjects [43].

5.4 Factors Affecting the Sensory Quality of Meat

Several factors can affect the sensory properties of meat, such as type of meat, genetic factors, production and rearing conditions, effect of postmortem practices, product preparation, and ingredients and warmed-over flavor (WOF). Some of them are detailed in the following sections.

5.4.1 Type of Meat

There has been a strong trend in the last decades for most industries to expand their horizons and compete at a global level. Therefore, research must be conducted with a global perspective, which means that the quality of meat must be assessed by consumers of different countries or cultures. In fact, the acceptance of meat is unique to different countries or cultures. In conducting cross-cultural consumer research, attention must be paid to the cultural nuances and language of the population being tested. Therefore, these studies involve the close collaboration of several researchers, who know the country being studied [8]. Committee E18 on Sensory Evaluation of the ASTM is working on a manual that will cover these issues extensively for different cultures across Europe, North and South America, and Asia. Furthermore, the rapid change in consumers' attitudes must be taken into consideration. The changes in consumer and market orientation have resulted from several factors, including increased health concerns, change in demographics, the need for convenience, changes in distribution and price of meat, among others [20,44].

5.4.1.1 Chicken Meat

Two consumer studies in Spain (3100 consumers) and Germany (2000 consumers) were organized in the year 2000 with the objective of validating in meat the food quality attributes proposed by

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

the European Community Association (ECA) as well as ranking them in order of importance. Safety, hygiene, and sensory characteristics were the most important meat quality characteristics as perceived by the consumers. Among the sensory characteristics, skin color of the chicken was considered very important [20,45].

Several consumer studies were conducted on chicken skin color. There was a significant preference for yellow-colored skin chickens sold in the open market of Guangdong, China (1993); the consumers were willing to pay even higher prices for the desired quality. In Barcelona, Spain (1999), a consumer survey in a supermarket indicated that 50% of the consumers associated yellow skin color with meat quality, 22% with fresh meat, and 11% with healthy birds. Additional consumer surveys have been carried out and published in South Africa and France where, once again, consumers showed their preferences for yellow broilers as synonymous of chicken meat quality [46]. Based on history and tradition, consumers consider color as an important quality attribute in poultry meat products. When given the choice, surveyed consumers from Europe and Africa always preferred the most intense golden yellow colors for chicken skin [45]. In France, 48% of the consumers preferred the yellow chicken skin, and the reasons were habit (32%) and quality/origin (29%). In Africa, 61% of the consumers preferred yellow chicken skin. They considered the color of the skin a very important quality aspect and were willing to pay extra for the preferred product (even 62% of the lower income group).

5.4.1.2 Pork Meat

In 2001, a book containing images of pork chops, based on a selection of 256 computer-modified images of pork chops differing in color, fat cover, marbling, and drip using digital photographs was published by Dransfield et al. [47] and Ngapo et al. [48]. Cho et al. [44] developed a novel methodology to conduct research for surveying consumer's preference of pork chops using the image book. Meat color was the most important characteristic; however, similar numbers of consumers chose the dark and light red colored pork. The presence of marbling and the absence of drip were also an important selection factor among characteristics for Korean consumers in choosing pork chops, whereas fat cover was not an important selection attribute. In a similar study undertaken by Ngapo et al. [48], French consumers also showed that color was the most important appearance attribute. However, fat cover was the second most important factor for the French consumer, with preference for lean meat.

5.4.1.3 Beef Meat

The role of the profile of fatty acids on the sensory perception of three muscles (longissimus dorsi, triceps brachii, and semimembranosus) from Korean Hanwoo and Australian Angus beef was investigated [49]. Cluster analysis showed that there was a significant difference in fatty acids (C16:0, C16:10, C18:0, C18:2n6, C18:3, C20:3n6, C20:4n6, C22:4n6, and C22:5n3) for tenderness, juiciness, flavor, and overall likeness of the beef from both origins. C14:0 had a significant effect on sensory perception only for Korean Hanwoo beef.

Lipid oxidation is one of the major causes of quality deterioration of processed meat, imposing an adverse effect on flavor, color, and texture. Furthermore, it causes a decrease in perception of meat flavor/odor and a concomitant increase in the off-flavor/odor described as linseed and rancid [50]. To relate humans' perception of lipid oxidation in beef, determined by a trained panel, to a chemical measurement of oxidation, Campo et al. [51] studied meat from animals with a

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

wide range of potential oxidation through differences in their polyunsaturated fatty acid (PUFA) composition. The meat was obtained from Angus and Charolais cross steers from different trials that had been raised on 10 different diets. Thiobarbituric acid reactive substances (TBARS) and sensory analysis were performed in longissimus dorsi muscle displayed under simulated retail conditions. Positive attributes, such as beef flavor or overall liking, decreased throughout display, whereas negative attributes, such as abnormal and rancid flavors, increased. The correlations between sensory and analytical attributes were high. TBARS were a good predictor of the perception of rancidity, and a TBARS value of 2 could be considered the limiting threshold for the acceptability of oxidized beef.

5.4.1.4 Goat Meat

The major demand for goat meat in the United States seems to come from various ethnic groups, influenced by their cultural traditions or religious beliefs [52]. In sensory studies conducted with consumers, goat meat generally was rated less desirable than other red meats. When oven-baked rib or loin samples were evaluated by five sensory panels (24–94 untrained panelists), goat meat was not markedly different in flavor desirability than beef or lamb, but tended to be less desirable in flavor than pork [53]. Overall satisfaction scores were lower for goat meat than pork, beef, or lamb.

In another study [54], goat and sheep meats (broiled loin chops and leg steaks) were evaluated by U.S. and foreign panelists (natives of China, India, Mexico, Taiwan, Saudi Arabia, Venezuela, or Vietnam). All the participants had eaten lamb and goat earlier and had expressed no dislike for either meat when asked before the sensory test session. Goat meat was rated lower than lamb and mutton in overall desirability, by both domestic and foreign panels. Flavor desirability ratings were similar for goat meat, lamb, and mutton, regardless of the panel makeup.

When pan-fried ground meat patties containing various levels of goat meat and beef were evaluated by 45 consumers (predominantly nongoat meat eaters), flavor desirability scores were highest for 20%-goat/80%-beef patties, followed by all (100%)-beef patties and 80%-goat/20%-beef patties, which received similar scores. All goat patties were given lower flavor desirability scores when compared to all-beef patties [55].

Plain meat loaves and chili were prepared with ground goat meat or beef containing 15% fat. Acceptability scores by a consumer sensory panel were similar for plain goat meat and beef loaves when the goat meat product was served before the meat product, but were lower for the goat meat with reverse serving order. In triangle tests, goat meat was differentiated from beef, whether plain or seasoned [52].

5.4.2 Genetic Factors

Sensory perception and technological quality of meat are highly influenced by both genetic and environmental factors. Crouse et al. [56] investigated the tenderness of meat traits of 422 steers differing in the ratio of Brahman, Sahiwal, or Pinzgauer to Hereford or Angus inheritance. *Bos indicus* breed crosses were less ($p < 0.01$) tender and more variable in tenderness than *Bos taurus* breed crosses. As the percentage of *B. indicus* inheritance increased, shear values increased and sensory panel tenderness scores decreased. Decreases in tenderness were associated with less desirable sensory panel ease-of-fragmentation scores and, to a lesser extent, with a sensory panel perception of more abundant connective tissue content of meat samples. Flavor characteristics were similar among all breed groups of cattle.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The effects of RN genotype on the sensory perception of cured-smoked loins were investigated in 30 female pigs crossbred with Hampshire. RN-carriers (RN^-/rn^+) were more tender, juicy, and acidic than noncarriers (rn^+/rn^+). They were also patty-like and less salty. Despite the superior eating quality, in terms of higher tenderness and juiciness, most consumers preferred cured-smoked loins from noncarriers [57].

5.4.3 Warmed-Over Flavor

WOF is recognized as a major quality concern by the food industry in the marketing of pre-cooked, ready to heat and serve products. It is characterized by a rapid oxidative deterioration that occurs in a variety of cooked foods during refrigerated storage. Byrne et al. [58] developed a list of 16 terms as a vocabulary to describe the aroma, flavor, and taste character notes of porcine meat samples (Table 5.6). This list resulted from an initial one containing 45 descriptive terms. Selection criteria were that the terms should have relevance to the product, discriminate clearly between samples, be not redundant, and have cognitive clarity to assessors. According to Byrne et al. [59], WOF development in cooked, chill-stored, and reheated pork patties made with musculus semimembranosus involved lipid oxidation, which caused off-flavor and odor notes, for example, rancid-like flavor and linseed oil – like odor, in association with a concurrent decrease in cooked pork meat-like flavor.

5.4.4 Production and Rearing Conditions

The production and rearing conditions of the animal can significantly affect the sensory perception of the meat. Rearing entire instead of castrated male pigs for meat production has a number of advantages including lower production costs, leaner carcass, lower output of nitrogen in the environment, and reduction of suffering for the animal. However, in most countries, male pigs are still castrated to avoid the potential problem of boar taint at a young age. Boar taint is an unpleasant odor/flavor that can be perceived when cooking/eating the meat from some entire male pigs. Consumer dissatisfaction for the odor of entire male pig was mostly associated with skatole (tryptophan metabolite) levels, with little influence of androstenone (testicular steroid androstenone). However, androstenone and skatole had similar contributions to the level of dissatisfaction for flavor [60–62]. Therefore, chemical measurements for skatole and androstenone were highly predictive of specific sensory descriptors of boar taint in cooked pork meat [63].

Trained analytical sensory panels in seven European countries, assessing pork meat with known levels of skatole and androstenone, were able to differentiate between the two compounds and among different levels of the compounds. Androstenone was found to relate mostly to urine attribute, whereas skatole related to manure and, to a lesser extent, to naphthalene [64]. Sorting carcasses on the basis of androstenone/skatole would reduce, but not eliminate differences in consumer dissatisfaction between entire male and gilt pork [65]. Chicory root (*Cichorium intybus* L.) feeding reduced the boar taint off-flavor in longissimus dorsi and psoas major muscles of intact male, and, therefore, can be considered to have the potential for utilization [63].

The influence of castration of entire male pigs of two different crossbreeds on the eating quality of dry-cured ham was evaluated by Banon et al. [66]. Sensory analysis was carried out by a trained panel, and preference and acceptability paired test was performed by consumers. Significant differences were found between entire and castrated animals for the mean values given in all investigated sensory attributes. The dry-cured ham from castrates was scored as more flavored, more marbled, and softer. It was also perceived as less grainy, less salty, and having less boar odor and flavor. Dry-cured

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 5.6 Sensory Descriptive Terms with Definitions Developed for the Evaluation of Warmed-Over Flavor Pork Meat

Sensory Attribute	*Definition with Reference Material*
Aroma	*Odor associated with:*
Cardboard-like	Shredded wet cardboard
Linseed oil–like	Warmed linseed oil
Rubber-like/sulfur-like	Warmed rubber or the white of a warm boiled and peeled egg
Flavor	*Aromatic taste sensation and taste sensation associated with:*
Cooked pork meat–like	Cooked pork meat
Rancid	Oxidized vegetable oil
Bread-like	The surface of French style bread
Vegetable oil–like	Fresh vegetable oil
Fish-like	Cod liver oil
Nut-like	Whole hazel nuts
Monosodium glutamate/umami	Monosodium glutamate, 0.05% in water
Metallic	Ferrous sulfate, 0.01% in water
Bitter taste	Quinine chloride, 0.005% in water
Sweet taste	Sucrose, 0.1% in water
Salt taste	NaCl, 0.05% in water
Sour taste	Citric acid, 0.03% in water
Aftertaste	*Chemical feeling factor on skin surfaces of oral cavity described as dry associated with:*
Astringent	Aluminum sulfate 0.002% solution in water

Source: Byrne, D.V., Bak, L.S., Bredie, W.L.P., Bertelsen, G., and Martens, M., *J. Sens. Stud.*, 14, 47, 1999. With permission.

ham from castrated males was also more accepted and preferred by consumers, especially women and habitual consumers. Castration of male pigs contributed to an improvement in the quality of dry-cured ham. The rejection caused by boar odor and flavor was reduced, improving the overall flavor, texture, and juiciness. In addition, saltiness was less pronounced in ham from castrates.

Sales of organically produced food have increased significantly in value throughout the world. Organic and conventional lamb loin chops from three major supermarket chains of the United Kingdom were analyzed for fatty acid composition, and eating quality was assessed by a trained sensory panel [67]. Organic lamb had a better eating quality than conventional lamb in terms of

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

juiciness, flavor, and overall liking. The differences in juiciness were attributed to the higher level of linolenic acid (18:3) and total n-3 PUFA in organic chops. Conventional chops had a higher percentage of linoleic acid (18:2).

Bryhni [68] investigated the influence of feed composition on pork meat sensory traits analyzed by a trained panel and by consumers. The quality of the pork influenced consumer satisfaction, and flavor was ranked by consumers as the most important sensory attribute. The presence of off-flavors indicated reduced liking for pork. The use of food wastes in the pig's diet did not affect sensory quality, but the back fat was darker and more susceptible to lipid oxidation. Pig dietary fatty acid composition affected fatty acid of the back fat and the trained panel sensory evaluation of both pork loin and sausage. Feeding a diet with low levels of fish oil or with high PUFA increased rancidity of the sausages.

Colditz et al. [69] investigated the impact of regrouped British breed steers 1, 2, and 4 weeks before dispatch for slaughter. Regrouping cattle less than 2 weeks before slaughter reduced meat quality. Also, the results confirmed the impact of flight time on growth rate during feedlot finishing.

5.4.5 Effect of Postmortem Practices, Product Preparation, and Ingredients on Meat Quality

Bryhni et al. [70] investigated the sensory quality and liking for pork as affected by pH, 24 h after slaughter, cooking temperature, and WOF among consumers (n = 288) in Scandinavia. The consumers preferred meat with higher pH (6.0), cooked to the lowest temperature (65 vs. 80°C). Samples with WOF were the least preferred and described as metallic, acidic, and off-flavor by a trained panel. Elevated-pH meat cooked to 65°C resulted in a sweeter and tender meat. Juiciness, tenderness, and the absence of off-flavor were the most important characteristics that governed the consumers' liking for pork. Consumption frequency and liking for pork were positively related. The most satisfied consumers reported highest consumption frequency. Elderly people and males expressed the highest liking score and consumption frequency, respectively.

Pork samples (longissimus dorsi) were cooked in an oven to a core temperature of 62 or 75°C and subsequently evaluated by a sensory panel. Juiciness and tenderness decreased with increasing temperature, while hardness, crumbliness, and chewing time increased. Such changes were associated with changes in the size of pores, confining the myofibrillar water together with an expulsion of water, determined by low-field nuclear magnetic resonance (NMR) T_2 relaxation [71].

A radio frequency cooking protocol was developed and its effect on the quality of pork-based white pudding was examined [72]. Results from a sensory similarity test involving 60 panelists indicated that they were not able to detect differences between radio frequency and conventional methods (water bath and steam oven heated products).

The irradiation of mechanically deboned chicken meat is of crucial importance to the safety of the industrial productive chain as well as to guarantee pathogen-free raw material. Gomes et al. [73] investigated the effect of gamma-radiation on the sensory characteristics of refrigerated mechanically deboned chicken meat. It was observed that the volatile compounds associated with the odor of irradiation procedures were dissipated from the samples during storage, and that the oxidation odor perceived in the samples irradiated with doses of 3.0 and 4.0 kGy was more pronounced than in the nonirradiated samples, as from the 8th and 12th day of refrigeration, respectively. Al-Bachir [74] investigated the influence of gamma-radiation in spices and packaging materials (10 kGy) and packaged luncheon meat (2 kGy) on the microbiological, chemical, and sensory characteristics of luncheon meat. Irradiation decreased the microbial counts and increased

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

shelf life without affecting moisture, protein, fat, pH, total acidity, lipid peroxide, and volatile basic nitrogen. Sensory evaluation showed that all the combinations of treated luncheon meats were acceptable; however, the taste, odor, appearance, and texture scores of irradiated packaged products were significantly lower than those of nonirradiated samples.

A time-intensity evaluation was performed to investigate the effect of texture and two different chili products on the intensity of oral burn and meat flavor of pork patties. The pork patties spiced with chili powder were perceived significantly hotter and with a less pronounced meat flavor than the minced chili patties. A multivariate model showed an agreement with univariate analysis that both chili products masked the meat flavor. No effect of texture was found on the perceived oral burn or meat flavor. Chili burn and meat flavor were perceived as less intense to regular eaters of chili compared to noneaters of chili [75].

5.5 Influence of the Improvement of Nutritional Value on Sensory Quality

Today there is a tendency of adding functional ingredients to meat products. Shiitake mushroom powder is one of a growing number of ingredients that have shown functional properties even in small amounts. It is a source of potassium, amino acids, and vitamins; furthermore, it has medicinal properties (used for cholesterol, tumors, and diabetes). Chun et al. [76] investigated consumer liking and perception of pork patties prepared with 0–6% shiitake mushroom powder and 0 or 0.5% sodium tripolyphosphate (STP—used to improve water-binding capacity). The patties made with both ingredients were acceptable by Korean consumers, but increases in mushroom powder in patties with STP decreased acceptability in the case of U.S. consumers. However, addition of mushroom powder to patties without STP increased acceptability for U.S. consumers, as it tended to increase texture acceptance and juiciness.

Textured soybean proteins (TSP) and other soy ingredients have been used in ground beef products to improve their functional properties and aid in reducing fat and cholesterol content, providing consumers with healthier products. Besides, there are potential cost savings in the production of ground beef, which can help bridging the high price barrier of animal products. However, the incorporation of high concentrations of TSP into meat can adversely affect flavor, color, and texture. Ground beef patties were processed replacing meat with hydrated and colored TSP (0, 15, and 30%), and the resulting cooked patties were evaluated by eight trained judges for tenderness, juiciness, number of chews, beef flavor, and overall flavor quality. The results indicated that ground beef patties with 15% TSP had sensory attributes similar to those of the control. However, patties with 30% TSP were tenderer than the control and had less beef flavor and overall flavor quality [77].

5.6 Concluding Remarks

Sensory properties (appearance, aroma, flavor, and texture) are the most important quality attributes driving consumers' choices for meat and meat products. However, cultural, religious, and food-related lifestyle can affect meat acceptance and expectation. Furthermore, there are several other factors such as brand, price, nutritional composition and information, production information, advertisement, convenience, safety, hygiene, and so on, which can create and affect the expectations and decisions toward meat purchase. Several of these factors and a flow chart describing the

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

role of expectations at the point of choice and during meat perception at the time of consumption are presented followed by scientific studies developed recently in the area.

Different models available to explain consumer expectations and demands are also provided along with their applications and advantages, as well as methods to investigate product sensory properties and acceptance. The demand for meat has changed over the years. Today, the nutritional quality (associated with lean products), convenience, and the movement from bulk to value-added products with a longer shelf life are probably the greatest trend of all. Several studies related to genetic improvement of meat quality, production and rearing conditions, postmortem practices, product preparation and incorporation of ingredients with functional properties, and their influence on meat acceptance have been conducted. Furthermore, their influence on shelf life and quality (WOF) have been discussed. The impact of product development with increased nutritional or functional properties on meat acceptance has also been illustrated. This has led to the development, production, and marketing of new meat products that appeal to the consumer, who is becoming more and more demanding about quality. Professionals in the industries must understand consumers' demands, perceptions, and attitudes to succeed and market the new product.

Abbreviations

ASTM	American Society for Testing and Materials
ECA	European Community Association
kGy	kilo gray
NMR	nuclear magnetic resonance
PUFA	polyunsaturated fatty acids
STP	sodium tripolyphosphate
TBARS	thiobarbituric acid reactive substances
TSP	textured soybean proteins
WOF	warmed-over flavor

References

1. Bredahl, L., Cue utilization and quality perception with regard to branded beef, *Food Qual. Prefer.*, 15, 65, 2003.
2. Bernués, A., Olaizola, A. and Corcoran, K., Extrinsic attributes of red meat as indicators of quality in Europe: an application for market segmentation, *Food Qual. Prefer.*, 14, 265, 2003.
3. Grunert, K.G., What's in a steak? A cross-cultural study on the quality perception of beef, *Food Qual. Prefer.*, 8(3), 157, 1997.
4. Oude Ophuis, P.A.M. and Van Trijp, H.C.M., Perceived quality: a market driven oriented approach, *Food Qual. Prefer.*, 6, 177, 1995.
5. Grunert, K.G., Future trends and consumer lifestyle with regard to meat consumption, *Meat Sci.*, 74, 149, 2006.
6. Bell, R. and Meilselman, H., *The role of eating environments in determining food choice*, in Marshall, D.W., Ed., *Food Choice and the Consumer*, Blackie Academic & Professional, Cambridge, UK, 292, 1995.
7. Grunert, K.G. and Valli, C., Designer-made meat and dairy products: consumer-led product development, *Livest. Prod. Sci.*, 72, 83, 2001.
8. Muñoz, A.M., Consumer perceptions of meat. Understanding these results through descriptive analysis, *Meat Sci.*, 1, S287, 1998.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

9. Steenkamp, J.B.E.M., Conceptual model of the quality perception process, *J. Bus. Res.*, 21, 309, 1990.
10. Cardello, A.V. and Sawyer, F.M., Effects of disconfirmed consumer expectations on food acceptability, *J. Sens. Stud.*, 7, 253, 1992.
11. Deliza, R., *The Effects of Expectation on Sensory Perception and Acceptance*, PhD thesis, The University of Reading, UK, 1996, 198.
12. Deliza, R., MacFie, H.J.H. and Hedderley, D., Evaluation of consumer expectation, in Almeida, T.C., Hough, G., Damasio, M.H. and Silva, M.A.A.P., Eds., *Avanços em análise sensorial*, Varela, São Paulo, Brazil, 1999, 111.
13. Behrens, J.H., Villanueva, N.D.M. and Silva, M.A.A.P., Effect of nutrition and health claims on the acceptability of soyamilk beverages, *Int. J. Food Sci. Technol.*, 42, 50, 2007.
14. Deliza, R. and MacFie, H.J.H., Product packaging and branding, in Frewer, L.J., Risvik, E. and Schifferstein, H., Eds., *Food, People and Society: A European Perspective of Consumers' Food Choices*, Springer-Verlag, Berlin, 2001, 55.
15. Martin, D., The impact of branding and marketing on perception of sensory qualities, *Food Sci. Technol. Today: Proceed.*, 4(1), 44, 1990.
16. Kopalle, P.K. and Lehmann, D.R., The effects of advertised and observed quality on expectations about new product quality, *J. Marketing Res.*, 32, 280, 1995.
17. Deliza, R. and MacFie, H.J.H., The generation of sensory expectation by external cues and its effect on sensory perception and hedonic ratings: a review, *J. Sens. Stud.*, 11(2), 103, 1996.
18. Issanchou, S., Consumer expectations and perceptions of meat and meat product quality, *Meat Sci.*, 43S, 5, 1996.
19. Schifferstein, H.N.J., Effects of products beliefs on product perception and liking, in Frewer, L.J., Risvik, E. and Schifferstein, H., Eds., *Food, People and Society: A European Perspective of Consumers' Food Choices*, Springer-Verlag, Berlin, 2001, 73.
20. Ressurreccion, A.V.A., Sensory aspects of consumer choices for meat and meat products, *Meat Sci.*, 66, 11, 2004.
21. Grunert, K.G., Bredahl, L. and Brunsø, K., Consumer perception of meat quality and implications for product development in the meat sector—a review, *Meat Sci.*, 66(2), 259, 2004.
22. Institute of Food Technology (IFT), *Minutes of Sensory Evaluation*, Division Business Meeting, 35th Annual IFT Meeting, Chicago, 1975.
23. MacFie, H.J.H., Assessment of the sensory properties of food, *Nutr. Rev.*, 48(2), 87, 1990.
24. Stone, H. and Sidel, J.L., *Sensory Evaluation Practices*, Elsevier Academic, San Diego, CA, 2004, 377.
25. McBride, R.L. and MacFie, H.J.H., *Psychological Basis of Sensory Evaluation*, Elsevier Science, New York, NY, 1990.
26. American Society for Testing and Material (ASTM), in Eggert, J. and Zook, K., Eds., *Physical Requirement Guidelines for Sensory Evaluation Laboratories,* ASTM Special Technical Publication 913, Philadelphia, 1986.
27. Meilgaard, M., Civille, G.V. and Carr, B.T., *Sensory Evaluation Techniques*, 3rd ed., Boca Raton, New York, NY, 1999, 354.
28. American Meat Science Association (AMSA), *Guidelines for Cookery and Sensory Evaluation of Meat*, Academic Press Inc., Chicago, IL, 1978.
29. MacFie, H.J., Bratchell, N., Greenhoff, K. and Vallis, L.V., Designs to balance the effect of order of presentation and first-order carry-over effects in hall tests, *J. Sens. Stud.*, 4, 129, 1989.
30. Plemmons, L.E. and Resurreccion, A.V.A., A warm-up sample improves reliability of responses in descriptive analysis, *J. Sens. Stud.*, 13, 359, 1998.
31. Murray, J.M., Delahunty, C.M. and Baxter, I.A., Descriptive sensory analysis: past, present and future, *Food Res. Int.* 36, 6, 461, 2001.
32. Langron, S.P., The application of Procrustes statistics to sensory profiling, in William, A.A. and Atkin, R.K., Eds., *Sensory Quality in Food and Beverages: Definitions, Measurement and Control*, Ellis Horwood Ltd., Chichester, UK, 1983, 89.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

33. Horsfield, S. and Taylor, L.J., Exploring the relationship between sensory data and acceptability of meat, *J. Sci. Food Agric.*, 27, 1044, 1976.
34. Muñoz, A.M. and Chambers, E., Relating sensory measurements to consumer acceptance of meat products, *Food Technol.*, 47, 11, 128, 1993.
35. Delores, H., Chambers IV, E. and Bowers, J.R., Consumer acceptance of commercially available frankfurters, *J. Sens. Stud.*, 11, 85, 1996.
36. Boleman, S.J., Boleman, S.L., Savell, J.W., Miller, S.K., Cross, R.H., Wheller, T.L., Koohmaraie, M., Shackelford, S.D., Miller, M.F., West, R.L. and Johnson, D.D., Consumer evaluation of beef of known tenderness levels, in *Proceedings of 41th International Congress of Meat Science and Technology*, Santo Antonio, TX, 1995, 494.
37. Miller, M.F., Carr, M.A., Ramsey, C.B., Crockett, K.L. and Hoover, L.C., Consumer threshold for establishing the value of beef tenderness, *J. Anim. Sci.*, 79, 3062, 2001.
38. Destefanis, G., Brugiapaglia, A., Barge, M.T. and Dal Molin, E., Relationship between beef consumer tenderness perception and Warner–Bratzler shear force, *Meat Sci.*, 78, 153, 2007.
39. Hough, G., Wakeling, I., Mucci, A., Chambers IV, E., Gallardo, I.M. and Alves, L.R., Number of consumers necessary for sensory acceptability tests, *Food Qual. Prefer.*, 17, 522, 2006.
40. Greenhoff, K. and MacFie, H.J.L., Preference mapping in practice, in MacFie, H.J.H. and Thomsom, D.M.H., Eds., *Measurements of Food Preferences*, Blackie Academic & Professional, London, UK, 1994, 137.
41. Berry, B.W. and Cicille, G.V., Development of a texture profile panel for evaluating restructured beef steaks varying in meat particle size, *J. Sens. Stud.*, 1(1), 15, 1986.
42. Deliza, R., *How to Understand and Interpret Consumer's Needs*, Short Course Notes, Embrapa Food Technology, Rio de Janeiro, 2007, 53.
43. De Graaf, C., Polet, P. and van Staveren, W.A., Sensory perception and pleasantness of food flavors in elderly subjects, *J. Gerontol.*, 49(3), 93, 1994.
44. Cho, S., Park, B., Ngapo, T., Kim, J., Dransfield, E., Hwang, I. and Lee, J., Effects of meat appearance on south Korean consumer's choice of pork chops determined by image methodology, *J. Sens. Stud.*, 22, 99, 2007.
45. European Consumer Association (ECA), http://www.esn-network.com/683.html, 1999.
46. Hernández Gimeno, J.M., Sensory perception of quality of products across Europe: a case study on poultry quality, http://www.esn-network.com/683.html, 2005.
47. Dransfield, E., Martin, J.F., Miramonte, J. and Ngapo, T.M., *Meat Appearance: Pork Chops. A Tool for Surveying Consumers' Preference*, INRA, Paris, France, 2001.
48. Ngapo, T.M., Martin, J.F. and Dransfield, E., Consumer choices of pork chops, *Food Qual. Prefer.*, 15(4), 349, 2004.
49. Cho, S.H., Park, B.Y., Kim, J.H., Hwang, I.H., Kim, J.H. and Lee, J.M., Fatty acids profiles and sensory properties of longissimus dorsi, triceps brachii, and semimenbranosus muscles from Korean Hanwoo and Australian Angus beef, *Asian-Aust. J. Anim. Sci.*, 18(12), 1786, 2005.
50. Nissen, L.R., Byrne, D.V., Bertelsen, G. and Skibsted, L.H., The antioxidant activity of plant extracts in cooked pork patties as evaluated by descriptive sensory profiling and chemical analysis, *Meat Sci.*, 68, 485, 2004.
51. Campo, M.M., Nute, G.R., Hughes, S.I., Enser, M., Wood, J.D. and Richardson, R.I., Flavor perception of oxidation in beef, *Meat Sci.*, 72(2), 303, 2006.
52. Rhee, K.S., Myers, C.E. and Waldron, D.F., Consumer sensory evaluation of plain and seasoned goat meat and beef products, *Meat Sci.*, 65, 785, 2003.
53. Smith, G.C., Pike, M.I. and Carpenter, Z.L., Comparison of the palatability of goat meat and meat from four other animal species, *J. Food Sci.*, 39, 1145, 1974.
54. Griffith, C.L., Orcutt, M.W., Riley, R.R., Smith, G.C., Savell, J.W. and Shelton, M., Evaluation of palatability of lamb, mutton and chevon by sensory panels of various cultural backgrounds, *Small Ruminant Res.*, 8, 67, 1982.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

55. James, N.A. and Berry, B.W., Use of chevon in the development of low-fat meat products, *J. Anim. Sci.*, 75, 571, 1997.
56. Crouse, J.D., Cundiff, L.V., Koch, R.M., Koohmaraie, M. and Seideman, S.C., Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability, *J. Anim. Sci.*, 67, 2661, 1989.
57. Hullberg, A., Sohansson, L. and Lundstrom, K., Sensory perception of cured-smoked loin from carriers and noncarriers of the RN– allele and its relationship with technological meat quality, *J. Muscle Foods*, 16, 54, 2005.
58. Byrne, D.V., Bak, L.S., Bredie, W.L.P., Bertelsen, G. and Martens, M., Development of a sensory vocabulary for warmed-over flavor: part I. In porcine meat, *J. Sens. Stud.*, 14, 47, 1999.
59. Byrne, D.V., Bredie, W.L.P., Bak, L.S., Bertelsen, G., Martens, H. and Martens, M., Sensory and chemical analysis of cooked porcine meat patties in relation to warmed over flavor and pre-slaughter stress, *Meat Sci.*, 59, 229, 2001.
60. Bonneau, M., Kempster, A.J., Claus, R., Claudi-Magnussen, C., Diestre, A., Tornberg, E., Walstra, P., Chevillon, P., Weiler, U. and Cook, G.L., An international study on the importance of androstenone and skatole for boar taint: I. Presentation of the program and measurement of boar taint compounds with different analytical procedures, *Meat Sci.*, 54, 251, 2000.
61. Matthews, K.R., Homer, D.B., Punter, P., Beague, M.P., Gispert, M., Kempster, A.J., Agerhem, H., Claudi-Magnussen, C., Fischer, K., Siret, F., Leask, H., Font i Furnols, M. and Bonneau, M., An international study on the importance of androstenone and skatole for boar taint: III. Consumer survey in seven European countries, *Meat Sci.*, 54, 271, 2000.
62. Weiler, U., Font i Furnols, M., Fischer, K., Kemmer, H., Oliver, M.A., Gispert, M., Dobrowolski, A. and Claus, R., Influence of differences in sensitivity of Spanish and German consumers to perceive skatole and androstenone concentrations, *Meat Sci.*, 54, 297, 2000.
63. Byrne, D.V., Thamsborg, S.M. and Hansen, L.L., A sensory description of boar taint and the effects of crude and dried chicory roots (*Cichorium intybus* L.) and inulin feeding in male and female pork, *Meat Sci.*, 79, 252, 2008.
64. Dijksterhuis, G.B., Engel, B., Walstra, P., Font i Furnols, M., Agerhem, H., Fischer, K., Oliver, M.A., Claudi-Magnussen, C., Siret, F., Béague, M.P., Homer, D.B. and Bonneau, M., An international study on the importance of androstenone and skatole for boar taint: II. Sensory evaluation by trained panels in seven European countries, *Meat Sci.*, 54, 261, 2000.
65. Bonneau, M., Walstra, P., Claudi-Magnussen, C., Kempster, A.J., Tornberg, E., Fischer, K., Diestre, A., Siret, F., Chevillon, P., Claus, R., Dijksterhuis, G., Punter, P., Matthews, K.R., Agerhem, H., Béague, M.P., Oliver, M.A., Gispert, M., Weiler, U., von Seth, G., Leask, H., Font i Furnols, M., Homer, D.B. and Cook, G.L., An international study on the importance of androstenone and skatole for boar taint: IV. Simulation studies on consumer dissatisfaction with entire male pork and the effect of sorting carcasses on the slaughter line, main conclusion and recommendations, *Meat Sci.*, 54, 285, 2000.
66. Banon, S., Gil, M.D. and Garrido, M.D., The effects of castration on the eating quality of dry-cured ham, *Meat Sci.*, 65(3), 1031, 2003.
67. Angood, K.M., Wood, J.D., Nute, G.R., Whittington, F.M., Hughes, S.I. and Sheard, P.R., A comparison of organic and conventionally-produced lamb purchased from three major UK supermarkets: price, eating quality and fatty acid composition. *Meat Sci.*, 78, 176, 2008.
68. Bryhni, E.A., *Consumer Perception and Sensory Analysis of Pork Flavor: Effect of Fatty Acid Composition and Processing*, DS thesis, Norway, 2002, 39.
69. Colditz, I.G., Fergunson, D.M., Greenwood, P.L., Doogan, V.J., Petherick, J.C. and Kilgour, R.J., Regrouping unfamiliar animals in the weeks prior to slaughter has few effects on physiology and meat quality in *Bos taurus* feedlot steers, *Aust. J. Exp. Agric.*, 47(7), 763, 2007.
70. Bryhni, E.A., Byrne, D.V., Rodbotten, M., Moller, S., Claudi-Magnussen, C., Karlson, A., Agerhem, H., Johansson, M. and Martens, M., Consumer and sensory investigations in relation to physical/chemical aspects of cooked pork in Scandinavia, *Meat Sci.*, 65(2), 737, 2003.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

71. Bertram, H.C., Aaslyng, M.D. and Andersen, H.J., Elucidation of the relationship between cooking temperature, water distribution and sensory attributes of pork—a combined NMR and sensory study, *Meat Sci*., 70(1), 75, 2005.
72. Brunton, N.P., Lyng, J.G., Cronin, D.A., Morgan, D. and Mckenna, B., Effect of radio frequency heating on the texture, color and sensory properties of a comminuted meat product, *Food Res. Int*., 38(3), 337, 2005.
73. Gomes, H.A., Silva, E.N., Cardello, H.M.A.B. and Cipolli, K.M.V.A.B., Effect of gamma radiation on refrigerated mechanically deboned chicken meat quality, *Meat Sci*., 65, 919, 2003.
74. Al-Bachir, M., The irradiation of spices, packaging materials and luncheon meat to improve the storage life of the end products, *Int. J. Food Sci. Technol*., 40(2), 197, 2005.
75. Reinbach, H.C., Meinert, L., Ballabio, D., Aaslyng, M.D., Bredie, W.L.P., Olsen, K. and Moller, P., Interactions between oral burn, meat flavor and texture in chili spiced pork patties evaluated by time-intensity, *Food Qual. Prefer*., 18(6), 909, 2007.
76. Chun, S., Chambers IV, E. and Chambers, D., Perception of pork patties with shiitake (*Lentinus edode* P.) mushroom powder and sodium tripolyphosphate as measured by Korean and United States consumers, *J. Sens. Stud*., 20, 156, 2005.
77. Deliza, R., Saldivar, S., Germani, R., Benassi, V.T. and Cabral, L.C., The effects of colored textured soybean protein (TSP) on sensory and physical attributes of ground beef patties, *J. Sens. Stud*., 17, 121, 2002.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 6

Sensory Aspects of Cooked Meats

Nelcindo Nascimento Terra, Rogério Manoel Lemes de Campos, and Paulo Cézar B. Campagnol

Contents

6.1 Introduction 87
6.2 Color 88
6.3 Texture 89
6.4 Flavor 92
References 95

6.1 Introduction

Organoleptic characteristics of meat determine the appeal it will have for consumers. The organoleptic quality of meat may be evaluated in a more objective way through instrumental or sensory methods used by scientists as measurement tools.

In cooked meat, flavor is one of the most important attributes. Many studies that have been conducted aimed at identifying volatile compounds responsible for its characteristic smell; there is lot of evidence substantiating the significant contribution of certain branched-chain fatty acids to it.

In regular storage conditions, color is the main appeal in meat. The color reflects the amount and chemical state of its main pigment, myoglobin. During cooking of meat, myoglobin is denaturated exposing the heme element and breaking the bond between the heme and the protein. However, the heme tends to form new bonds with the denatured myoglobin and other denaturated myoglobin.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The formation of the bond between the heme and the denaturated proteins, different from myoglobin, may occur during the first stages of myoglobin denaturation when the heme is partially exposed, since the myoglobin precipitation on the meat happens at lower temperatures than those of pure solutions. The hemychrom pigment with the denaturated protein, Fe^{2+} as Fe^{3+}, which is formed during cooking, gives the cooked meat a brownish color. The general precipitation of proteins increases the light diffusion on the surface and is responsible for the light color appearance of the cooked meat.

Meat texture is a sensory parameter that has the primary attributes such as softness, cohesivity, viscosity, and elasticity; secondary ones such as thickness, masticability, juiciness, fracturability, and adhesivity; as well as the residual ones such as velocity of break, humidity absorption, and cold sensation in the mouth. The most important attributes for meat texture are softness, juiciness, and masticability. Some scientists use the term "tenderness" for softness, when dealing with physical measurements of the cooked meat resistance to compression or bond strength, and "sensory tenderness" to describe the resistance to mastication detected by the tasters.

6.2 Color

The raw meat presents red color because of the myoglobin, a chromoprotein responsible for the fixation of oxygen in the muscles of live animals. Since there is no meat without blood, the hemoglobin present in it also contributes, in a little amount, to the red color of the meat.

Myoglobin consists of a protein portion (globin) attached to the heme group that contains, in its central portion, an atom of iron whose electronic lability facilitates the creation of other pigments with colors different from red, characteristic of meat. Myoglobin is found in meat in three main forms: deoxymyoglobin, oxymyoglobin, and metmyoglobin. Both deoxymyoglobin and oxymyoglobin are physiologically active, due to the action of the metmyoglobin reductase enzyme. This action declines in the postmortem.[1] Deoxymyoglobin is found in the central portion of the meat cuts, where oxygen is not present. When iron changes from ferrous to ferric, the metmyoglobin, which is a brown-colored pigment, is created. The oximyoglobin, resulting from the oxygenation of myoglobin, is responsible for the bright red color of raw meat.[2]

The behavior of these pigments under the action of heat determines the color of cooked meat. The heating determines the denaturation of the globin that precipitates with other meat proteins; in other words, this denaturation is a function of temperature.[3] The treatment of meat is a technological need, either for eliminating the pathogenic flora or for decreasing the saprophyte flora, as well as to produce meat products. In this condition, while globin is denaturated the metmyoglobin creates the hemichromogen globine (brown color) also known as ferrihemochrome.

The meat color can be measured visually, chemically, or instrumentally. In the first case, sensory panels are used, whereas the typical instrumental technique is based on chroma meter searching for the values of L (brightness), a (red tendency), and b (yellow tendency), known as Hunter values. Technological procedures usually need the quantification of pigments in meat because these are directly related to the final color of cured meat products.

In procedures described by Terra and Brum,[4] the meat pigments are extracted in acidified acetone using the following technique: weighing 10 g of the sample in a 100 mL beaker, adding the solution consisting of 40 mL of acetone and 3 mL of distilled water, mixing it for 5 min without light, and filtering it through Whatman number 1 filter paper. The optic density (OD) can be quantified in spectrophotometer at 540 nm, applying a mixture with 80% of acetone and 20% of distilled water as "a blank." By multiplying the OD by 290, the nitrous pigment in ppm

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

is obtained. To quantify the gross pigments, 10 g of the sample is measured in a beaker. To this sample 40 mL of acetone, 2 mL of distilled water, and 1 mL of concentrated chloride acid are added. This is then mixed using a glass stick, covered with a clock glass, and kept in dark for 1 h, followed by filtration and measurement of the OD at 640 nm. A mixture containing 80% of acetone, 2% of concentrated chloride acid, and 18% of distilled water is used as white. The gross pigments are obtained by multiplying the optic densities by 680. The heat induces changes in the meat because its components are dependent on the temperature and time of cooking to have a higher or lower effect on softening.[5] Cooking the meat induces structural changes that lessen the water retention capacity reflecting mainly on the juiciness.[6]

6.3 Texture

Many techniques are used to cook the meat because the variation in the time of cooking and the palatability does not allow the use of one single technique. The use of microwaves provides fast heating rates,[7] meat tenderness, with fewer flavors and inferior cooking performance, when compared to conventional techniques.[8] The use of ultrasound in the cooking of meat has been shown to be a fast and efficient method to improve the attributes of meat texture.[9] The mechanical properties of meat affect the proteins of the conjunctive tissue and collagen. The texture of meat is influenced not only by the quantity of collagen, but also by its solubility in the heating.

The heat induces changes in the muscle, and its components are dependent on the temperature and the time of cooking. The effect on hardness or softness is influenced by the process.[5] The loss of structure of the perimysium in the cooked meat is due to the shrinking and the denaturation of the collagen fibers.[10] Granule deposits are observed in the openings between the endomysium and the myofibrillar mass, which are from the plasmolemma, which in turn are noncolloidal particles. The presence of granules indicates the passive fat of the fibrillar muscle.

These extensive deposits are due to the rupture (distortions) of the endomysium and perimysium that occurs inside the cooked meat at high temperatures.[5] This loss of myofibrillar structure is due to the progressive distortion of the endomysium and perimysium during cooking, which also causes distortions in the myofibrillar mass, conducting this way the loss of the structural integrity. This happens due to the softening of the collagen from the endomysium, which causes the rupture of the fiber and the progressive weakening of the adhesion between them. All these qualitative alterations indicate progressive changes of denaturation inside the collagen, which leads to the softening of the meat.

Discontinuity and the marked distortions of the endomysium and perimysium with loss of structural integrity were observed in meat cooked under pressure. Palka[11] observed this in the semimembranosus muscle of bovines, cooked at 80–90°C. The texture of the cooked meat may also be altered by an increase in humidity.[12] The presence of an amount of intramuscular fat increases the juiciness and the flavor of cooked meat.[13] The thermal conditions (internal temperature) during the cooking of the meat have a significant effect on all parameters of the meat texture profile (cohesivity, elasticity, adhesivity, hardness, and masticability), reaching its best level in the scale between 70 and 80°C.[6]

Researches by Palka and Daun[14] reported that increasing the temperature of cooking to 100°C makes the structure of the meat turn into something like a compact case due to a significant decrease in the diameter of the fiber. Vasanthi et al.[5] cooked buffalo meat at 100°C for 45 min in water and achieved a softness, if compared with other techniques, similar to that obtained with cooking under pressure. Straadt et al.[15] used the combination of confocal laser microscopy with the nuclear magnetic resonance to visualize the changes in the meat during the aging and heat

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

treatment, characterizing the water distribution among the muscular fibers. These authors concluded that the combination of these methods is ideal for acquiring basic information about the microstructure and the structural changes of fresh and cooked meat.

Sensory attributes of foods are of great importance to the preference, which is affected by endogenous factors (hereditary, sex, age, and activity) as well as exogenous ones (culture, society, and economy);[16] the instrumental tests and determinations are generally faster, simpler, and exact, while the sets of information about the quality of the food are not sufficient.[17] The relation between the sensory attributes and the instrumental techniques is another field under investigation;[18] thus, an analysis must help the other to ensure the quality of the elaborated products. Nicod[19] describes that many phases are necessary to obtain a sensory evaluation group. These include recruiting, preliminary selection, specific selection, and training and control of the group (confidence in the answers, individual and collective repetition, etc.). The consumer when buying food, such as meat or a meat product, looks for all the answers to his/her patterns of smell, taste, color, appearance, and texture; and for the description of these attributes, he/she may use a trained panel of tasters.

The texture of a food is a multidimensional property that is defined as the set of mechanical, geometric, and surface properties of a product, perceivable by the mechanic receptors, the tact receptors, and, in some way, the hearing receptors.[20] More recently, Szczesniak[21] defined texture as the sensory and functional manifestation of the structural, mechanic, and surface properties of foods, detected through the senses of vision, hearing, tact, and smelling. This affirmation leads to important concepts.[22] (1) Texture is a sensory characteristic; thus, only human beings and animals may perceive it. The measurement instruments can only detect and quantify certain physical parameters that soon shall be interpreted in terms of sensory concepts. (2) It is a multiparametric attribute. (3) It is derived from the food structure (molecular, microscopic, or macroscopic). (4) It is detected by many senses, the tact being the most important.

Texture is one of the attributes evaluated by a customer for accepting a certain type of meat; it is determined mainly by the presence of proteins of the connective tissue and of myofibrils.[23]

The increase in texture caused by the proteins of the conjunctive tissue is explained by the formation and stability of the crossed bridges of the collagen molecule established with the aging of the animal. There are many factors that influence the softness of the meat, such as genetic characteristics, physiologic factors, type of feeding, how the animals are raised, and, specially, the physical-chemical state of the meat, which is closely related to the previously mentioned factors. The texture promoted by the myofibrillar proteins is affected by the development of the rigor mortis and depends on the carcass formation that may promote the softening of the meat by proteases. The structural organization of the muscle proteins is decisive to the distribution of water inside the meat and this way it has a direct effect on the characteristics of the meat.[24,25]

Hardness depends mostly on the quantity of connective tissue of the meat and on the stability of unifying points among the many molecules of collagen, such as the level of shortening of the sarcomere.[26] The collagen is a major protein inside the conjunctive tissue that is present in the muscle, encircling every muscular fiber (endomysium) to every fiber beam (perimysium) and to the muscle set (epimysium). Collagen is formed by helicoidal protein molecules that appear in groups of three by three, coiling one over the other to form molecules of tropocollagen.

One of the possibilities to improve the uniformity of texture consists in homogenizing the raw material destined to a determined process.[27] Among the parameters of raw material that affect the texture, the important ones are: the content of intramuscular fat;[28] its composition in fatty acids;[29] the pH of the muscles and the proteolytic potential of the meat;[30] the residual enzyme activity of cathepsin B in raw material;[31] the residual enzyme activity of cathepsins B + L;[32] the genotype;[33] the weight and feeding of the animals; the conformity and type of cut; the postmortem time and

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

the process of freezing the meat; the storage and defrosting of the meat;[27] the electric stimulation of the meat;[34] and the method of cooking,[35] among others.

It is also possible to use sensory tests to evaluate the texture of a food. In this technique, the evaluation of texture is done by means of a panel of trained tasters; this measure is going to be the closest to what the costumer will get when consuming the food and, therefore, the best prediction of customer acceptance. There is no doubt that having an analytical tool like this is not always possible, since it usually results in high cost, effort, time and money. Thus, it is not remarkable that some laboratories and companies prefer the instrumental measurers to be able to estimate the texture characteristics that will define their product quality.

Many instrumental methods are developed to determine the texture of food.[36] In general, the instrumental measure of the texture in food implies the use of mechanical tests that can replace the sensory panels imitating or trying to reproduce the way they measure.[37] From the instrumental methods of measure, the imitative methods are based on the concept of texture and its characteristics, described by Szczesniak.[38]

The objective of these methods is to determine the profile of the texture in a certain food, measuring instrumentally distinct parameters. There are many methods that may be classified as imitative; however, the most used among them is the instrumental texture profile (TPA, texture profile analysis), for its good correlations with the sensory quantification, and hardness is the most studied measure about meat and its derivatives.[22] This method imitates the circumstances under which the food is submitted during the chewing process.[39] In this test the mechanical characteristics correlate to the reaction of the food to the effort and obtained primary parameters such as hardness, cohesivity, viscosity, elasticity, and adhesivity, besides secondary parameters such as fragility, masticability, and thickness.[38]

This technique consists of compressing the food sample (meat samples, for example, cut in slices of approximately 1.5 cm of length and 2.5 cm of width) in a texturometer or between two plain surfaces, two times consecutively, with the equivalent strength used in a bite, with the objective of imitating the action of chewing. The parameters of TPA (hardness, masticability, elasticity, and cohesivity) according to the strength–time curves were detailed by Breene[40] and Bourne.[39] Once a 5 kg weight is applied, the same procedure is conducted with the compression probe making it reach down to the plate where the sample is put. In the compression test we apply two consecutive bites, obtaining a graphic where the time of the test (abscissa) represents the function of the applied strength (ordinate). The conditions in the analysis are the following: 2.0 mm/s for the velocity of the probe in compression; 10.0 mm/s for the velocity of the probe rising; and 50% for the degree of compression of the sample. When the test is realized, the following texture parameters are defined:

Hardness: It is defined as the necessary strength to compress a substance between the teeth or between the tongue and the palate, depending on the kind of the product. It is taken from the height of the higher peak in the first compression of the TPA curve. It is expressed in grams (g).

Cohesivity: It is equivalent to the unifying strength that keeps connected distinct parts of a food giving the structure of the sample, that is, the degree to which a substance is compressed between the teeth before it is torn apart. It is calculated as the relation between the two positive areas in a strength–time curve. It is an adimentional parameter.

Elasticity: It is the distance between the first and the second contact of the probe with the sample, that is, the degree in which the sample, once deformed, recovers its initial nondeformed condition when the deformation forces are suspended. It is expressed in nm.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Adhesivity: It is equivalent to the work necessary to overcome the attraction forces between the surface and the sample, when they get in contact. It is reflected in the area of the curve that may appear under the baseline after the first cycle of compression (first bite). It is measured in g × s (seconds).

Masticability: It is the energy required to chew the sample, reducing it to an adequate consistence for swallowing. It is calculated from the measures of hardness, cohesivity, and elasticity. It is expressed in g × mm.

The parameters of compression obtained with TPA are used by many authors to evaluate the meat and its derivatives, as a rate to determine the quality of the products or to select the best functional formula.[41–44] The compression test was used to study the mechanical properties of the muscle fibers. Many authors used the test of compression to monitor the mechanical properties of myofibers during the beginning of the rigor mortis and after it.[45]

More recently, Christensen et al.[46] applied this test to study the changes in the mechanical properties of fibers during the storage postmortem. Some authors employed tests of meat compression in fibers from the muscle and the conjunctive tissue, the perimysium, to determine the effect of the cooking temperature.[47,48]

In meat and in meat products, something similar occurs, even if there are clear preferences depending on the kind of meat and if it is consumed as fresh meat or as a meat product.[30] For pork meat the flavor and the texture seem to have similar importance when the product is not excessively dry and fibrous, situation in which the texture properties result determined. From the attributes of palatability of the meat, the softness is evaluated as the most important factor and a great amount of research has been done to improve this attribute.[5] The intramuscular fat influences the texture, juiciness, and flavor, thus playing an important role in the perception of meat quality.[13]

In irradiated pork meat, the characteristic smell is caused by the production of sulfur volatiles from sulfurous amino acids, such as methionine and cysteine.[49] The chemical changes in irradiated meat are initiated by sulfur free radicals or carbon monoxide resulting from reactions among meat components and radiolytic free radicals.[50]

Ruiz de Huidoro et al.[51] have tested two methods to determine the meat texture and concluded that in raw meat, TPA method is more useful than Warner–Braztler's (WB) test, and when such a method is applied to cooked meat the contrary is observed.

People are familiar to the basic five senses: sight (eyes), taste (tongue), smell (nose), hearing (ears), and touch (fingers and mouth sensation). The touch, responsible for mouth sensation, may be decomposed into three sensations: pressural, trigeminal, and kinesthetic. The pressural represents the sensation that is experimented when a force is applied to the food surface; trigeminal refers to pain sensation; and kinesthetic means retrofeeding from muscles of mastication during chewing process.[52]

6.4 Flavor

While purchasing, the consumer first checks food appearance and color, later on the smell. Finally, during the process of mastication he/she checks its texture, taste, and smell, which all together determine the final impression on flavor.[53] Flavor impression is caused first by food nonvolatile compounds, interacting with the tongue surface, palate mucosa, and tongue areas. Smell impression is caused by volatiles that evaporate from the food during mastication process and dislocate to the nasal cavity, where they react with olfactory sensors producing an electric signal, which is transmitted to the olfactory bulb in the frontal brain cortex.[53] Volatile concentrations with low molecular weight may sensitively affect the smell.[54]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Buck and Axel, who were awarded Nobel Prize in Physiology/Medicine, have shown how the signal, detected in the nose, is transmitted to the brain. First, the signal is sent to the olfactory bulb in the brain, which works as an initial piece of information organization center. Even though neurons are randomly distributed in the nose, the ones that carry the same type of receptive protein connect at the same fixed point in the olfactory bulb; therefore, there is a topographic map in the olfactory bulb where each one of the thousands reception proteins is represented and in which the smell activates the only combination between these points. Afterwards, this set of information is sent to the "superior" parts of the brain, where the conscious smell perception is generated, or to the "primitive" brain structures, which rule the inborn behavior, emotions, and memory. It is estimated that human beings are sensitive to 5,000–10,000 aromatic compounds.[55]

Up to now, more than 2600 chemical substances are known as smell volatile components. They are organic compounds of low molecular weight (less than 300), which are partially lipid soluble. Many of these compounds were identified after the invention of the gas chromatograph (GC). It is feasible to only identify and quantify the volatile compounds of a food without setting the direct contribution of individual compounds to flavor.[52] Different chemical groups add smell to the meat, such as aldehydes, alcohols, ketones, acids, esters, lactones, furans, phenols, terpenes, sulfur compounds, and so on.

The meats are cooked, desiccated, or even smoked, aiming at developing the flavors. The application of heat produces complex reactions among the amino acids (frequently those with sulfur) and sugars (which contain carbonyl) producing the Maillard reaction.[52] The time in which the meat is cooked, either using a dry method (roasting) or, a humid one, and the temperature reached during the cooking process may change the formed compounds and drastically change the *flavors*.

Taking into consideration that cooking methods give place to different flavor reactions, in each animal there is a singular relation of amino acids, fatty acids, and sugars, generating, this way, its own flavor. In bovines, sheep, and pig, the lipids have mainly saturated fatty acids, which do not degrade as fast as the unsaturated fatty acids. The poultry and fish have a great amount of unsaturated lipids, which generate flavor and small chemical molecules that interact with the products from the reaction of amino acids with sugars, forming more complex flavors. The taste of rancidity is developed more easily in fish and poultry due to such unsaturated lipids.

During water heating, many flavors are modified as well as new ones appear from nonvolatiles precursors. This way, these changed flavors, caused by the cooking process, are part of a different category. The thermal decomposition of the amino acids and peptides require higher temperatures than the ones normally applied while cooking the food. In roasted food only the superficial areas, where dehydration occurs, allow the temperature to significantly increase, over the boiling point of water, leading to decarboxylation and desamination of the amino acids, with the consequent formation of aldehydes, hydrocarbons, nitriles, and amino compounds.

The Maillard reaction is one of the most important means for the formation of flavor compounds in meat and meat products, constituting the basis for numerous patents for the industrial production of meat flavors.

Louis Maillard, a French chemist, discovered in 1912 the reaction between sugars and amino acids, while working on color compounds (melanoidins), formed by heating a solution of glucose and glycine. The reaction basically involves a protein compound (protein, peptide, amino, or amino acid) and a sugar.[56] Although apparently simple, the Maillard reactions are very complex because they comprise condensation, dehydration, reordering, and degradation to form furans, furfural and derivatives, aldehydes, dicarboniles, cetons, and so on. These compounds may undergo new reactions among themselves or with some other lipid carbonylic compounds to generate many volatile compounds (secondary reactions).

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The Maillard reaction does not demand high temperatures as the ones for caramerization and pyrolysis of proteins. Frozen sugar and amino acid mixtures show, within the time, Maillard darkening. No doubt that the reactions of Maillard occur at higher speed and temperature, mainly temperatures that correspond to cooking, thermal processing, and desiccation.[52] The speed of the reactions also increases at low humidity. Therefore, flavor compounds produced by the Maillard reaction tend to associate with the surface of the foods that were dehydrated by heat.

The first step of the Maillard reaction consists of the addition of the carbonyl group of an open-chain reductive sugar to the amino group of an amino acid or peptide (a primary amino group). From the subsequent elimination of distilled water results a Schiff base. Water is the limiting factor, and over this phase, the reaction is irreversible; the set of oxidation and Maillard reactions generate a large number of volatile compounds that may group in the following categories: carbonyls (aldehydes and ketones), furans, fatty acids, pirazines, and sulfur compounds (sulfurs, thiazoles, thiols, and thiophenols).[57] The final flavor is determined by the set of all volatile compounds, considering their concentrations, minimal detection number, and so on.[56]

Strecker reactions characterize another set of volatile compounds such as 2-methyl propanal, 2-methyl butanal, and 3-methyl butanal, which derive from valine, isoleucine, and leucine, respectively.[57] Sulfur volatile compounds are also formed from amino acids rich in sulfur such as methionine, cysteine, and cystine.

Rancid flavor of the deteriorated fat is due to the lipid autoxidation of the unsaturated fatty acids. The course of the reaction is the same if the acids are esterified or free and occurs in three steps. Initiation step produces a small number of highly reactive free radicals (molecules with unpaired electrons).

In the propagation step, the oxygen reacts with the free radicals produced in the initiation step, forming hydroperoxides, which degrade to generate more free radicals that can attack more fatty acids and react with more oxygen to result in a chain of reactions. When the concentrations of free radicals are formed, they tend to react among themselves to form stable final products, a characteristic of the rancified fat: aldehydes, alcohols, and cetons. The oxidation reactions with the formation of free radicals that are produced while cooking, as well as rancidity, follow the same basic paths previously described and generate similar types of volatile products.

There are differences in the precise mechanisms of oxidation in refrigeration or heating conditions. In cooking, the reactions contribute to the agreeable taste, while in rancid products, the radical reactions produce undesirable flavors. Hydroperoxides are extremely thermolabile. At lower temperatures they are more stable and are formed in a higher amount before their decomposition. Different proportions of the many intermediate radicals are formed, resulting in different volatile products.

Aldehydes and ketones produced by lipid oxidation may also undergo secondary reactions in the presence of amino acids, generating other flavor compounds. Lipid oxidation in cooking plays an important role in the development of the complex flavor profile of the meat volatiles; in slightly cooked or roasted meats, especially in poultry, during processing and storage of the food, polyunsaturated fatty acids (PUFAs) tend to be oxidized.[58] The lipid autooxidation also occurs during long-term meat storage, producing strange and undesirable flavors. The heating flavor becomes evident when cooked meats are kept at refrigeration temperature, for a few days, and after that are reheated, a phenomenon that is attributed to lipid oxidation products. It is believed that it is due to the autoxidation of the phospholipids, which are more unsaturated than the triglycerides. During the initial heating, the rupture and disintegration of the membranes of the muscular cells leave the phospholipids more susceptible to oxidation. This reaction is catalyzed by metallic ion traces, iron in particular, proceeding from the degradation of the heme pigments during cooking.[52]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Cooking the meat results in a product with different appearance due to the alteration of characteristics such as texture, taste, and smell. The appearance of cooked meat may be influenced by the pH, origin of the meat (animal species, animal age, and anatomic position of the muscle), quality of processing, fat rate, additives, packaging conditions, and conservation treatments (heating, irradiation, and pressure).[3] Cooked meat is more susceptible to lipid oxidation than raw meat, during its storage, considering that the heating operations alter the muscle endogenous prooxidative/antioxidative balance, mixing the oxidation catalyzers with the lipid, thus promoting the myoglobin oxidation, liberating iron to the limit, inactivating the antioxidizing enzymes.[59] Meat cooking promotes the formation of smell compounds from lipids during the process of oxidation, Maillard reaction, and interactions among the reaction products.[60]

The heat releases the iron ion from the heme pigment, which is known to be an important catalyzer to the oxidation of lipids in cooked meat.[61] The oxidation induced by the heat produces degradation products such as aldehydes, ketones, and aliphatic alcohols, which lead to undesired tastes.[62] The potential losses of n-3 PUFA during the processing and cooking of the meat could be significant. The cooking of the meat may lead to a loss or to an alteration of fatty acids, specially the PUFAs; however, data concerning the effect of cooking chicken meat in relation to the quantity and type of fatty acid left after cooking are inconsistent. The same authors suggest that the more aggressive thermal processes may cause significant losses of PUFAs. Elmore et al.[62] report that this lower concentration of fatty acids reduces the oxidizing stability, resulting in alterations in the volatile composition of the aroma produced during cooking.

The flavor of the cooked meat decreases sharply during the storage, due to formation of free radicals by oxidation of intramuscular phospholipids of the membranes, which contain relatively high levels of polysaturated fatty acids. The retention of the flavor in meat is a little problematic, and shows that the high concentrations of free phospholipids in turkey chest are more susceptible to oxidative deterioration than other meats. Studies carried out by Insausti et al.[13] revealed differences in the volatile compounds in beef of autochthonous Spanish breeds, which may contribute to the taste and smell in the cooking of the meat.

Baek and Cadwallader,[63] using the technique of headspace gas chromatography/mass spectrometry, found in alligator cooked meat 56 volatile compounds, including 23 aldehydes, 10 alcohols, 11 ketones, 9 terpenes, and 3 varied compounds. The aliphatic saturated aldehydes derive from the oxidative degradation of the PUFAs and normally have an unpleasant smell. Based on the results obtained, it can be concluded that some oxidation occurred after the meat was cooked. Thus, the lipid oxidation must be avoided to improve the aroma of the cooked meat.

References

1. Warriss P. *Meat Science: An Introductory Text*. Oyon: Cabi Publishing; 2000.
2. Varnam A, Sutherland I. *Meat and Meat Products*. London: Chapman & Hall; 1995.
3. King N, White R. Does it look cooked? A review of factors that influence cooked meat color. *Journal of Food Science* 71, 31–40; 2006.
4. Terra NN, Brum MAR. *Carne e seus derivados*. São Paulo: Nobel; 1988.
5. Vasanthi C, Venkataramanujam V, Dushyanthan K. Efect of cooking temperature and time on the physico-chemical, histological and sensory properties of female carabeef (búfalo) meat. *Meat Science* 76, 274–280; 2007.
6. Barbera S, Tassone S. Meat cooking shrinkage: Measurement of a new meat quality parameter. *Meat Science* 73, 467–474; 2006.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

7. Bakanowski SM, Zoller JM. End point temperature distribuitionss in microwave and conventionally cooked pork. *Food Technology* 38, 45–51; 1984.
8. El Shimi NM. Influence of microwave and conventional cooking and reheating on sensory and chemical characteristics of roast beef. *Food Chemistry* 45, 11–14; 1992.
9. Pohlman FW, Dikeman ME, Zayas JF, Unruh JA. Efects of ultrasound and convection cooking to diferent end point temperatures on cooking characteristics, shear force and sensory properties, composition and microscopic morphology of beef Longissimus and Pectoralis muscles. *Journal of Animal Science* 75, 386–401; 1997.
10. Lewis GJ, Purslow PP. The strength and stiffness of Perimysial connective tissue isolated from cooked beef muscle. *Meat Science* 26, 255–269; 1989.
11. Palka K. The influence of post-mortem ageing and roasting on the microsctructure, texture and collagen solubility of bovine *semitendinosus* muscle. *Meat Science* 64, 191–198; 2003.
12. Farouk MM, Swan JE. Boning and storage temperature effects on the attributes of soft jerky and frozen cooked free-flow mince. *Journal of Food Science* 64, 465–468; 1999.
13. Insausti K, Gon V, Petri E, Gorraiz C, Beriain MJ. Effect of weight at slaughter on the volatile compounds of coged beef from Spanish cattle breeds. *Meat Science* 70, 83–90; 2005.
14. Palka K, Daun H. Changes in texture, cooking losses, and miofibrillar structure of bovine M. Semitendinosus during heating. *Meat Science* 51, 237–243; 1999.
15. Straadt IK, Rasmussen M, Andersen J, Bertram HC. Aging-induced changes in microstruture and water distribution in fresh and cooked pork in relation to water-holding capacity and cooking loss—A combined confocal laser scanning microscopy (CLSM) and low-field nuclear magnetic resonance relaxation study. *Meat Science* 75, 687–695; 2007.
16. Risvik E. Sensory properties and preferences. *Meat Science* 34, 67–77; 1994.
17. Soriano AP, Quiles RZ, Garcia R. Selección, entrenamiento y control de un panel de análisis sensory especializado en jamón curado. *Eurocarne* 99, 25–34; 2001.
18. Elortondo FGP, Eguía PB, Aguado MA. Análisis sensory en quesos con denominación de origen. *Alimentaria* 309, 165–167; 2000.
19. Nicod H. L'organisation practique de la mesure sensorielle. La formation du groupe, en Evaluation sensorielle. *Manuel mèthodologique, SSHA et ISHA*. Paris: Technique et Documentation-Lavoisier; 1990.
20. ISO. Sensory Analysis. *Vocabulary*. ISO 5492, 1–36; 1992.
21. Szczesniak AS. Texture is a sensory property. *Food Quality and Preference* 13, 215–225; 2002.
22. Ruiz-Ramírez J, Gou P, Arnau J. Textura en productos cárnicos crudos curados: medidas instrumentales y sensoryes. *Eurocarne* 116, 95–106; 2003.
23. Shimokomaki M, Ida EL, Kriese PR, Soares AL. Calpaínas e Calpastatinas. In: Shimokomaki M, Olivo R, Terra NN. *Atualidades em Ciência e Tecnología de Carnes*. Sao Paulo: Livraria Varela; 2006. pp. 185–194.
24. Melody JL, Lonergan SM, Rowe LJ, Huiatt TW, Mayes MS, Huff-Lonergan E. Early post mortem biochemical factors influence tenderness and water-holding capacity of three porcine muscles. *Journal of Animal Science* 82, 1195–1205; 2004.
25. Huff-Lonergan E, Lonergan SM. Mechanisms of waterholding capatity of meat: the role post mortem biochemical and structural changes. *Meat Science* 71, 194–204; 2005.
26. López-Bote C. Calidad de la carne. In: Martín Bejarano S. *Manual práctico de la carne*. Madrid: M & M Ediciones; 1992. pp. 143–180.
27. Arnau J, Gou P, Comaposada J. Control del secado para uniformizar la textura del jamón curado. *Eurocarne* 115, 51–58; 2003.
28. Virgili R, Porta C, Schovazappa C. Effect of raw material on the end-product characteristics. *44th ICoMST*. Barcelona; 1998. pp. 26–38.
29. Ruiz-Carrascal J, Ventanas J, Cava R, Andrés AI, García C. Texture and appearance of dry-cured ham as affected by fat content and fatty acid composition. *Food Research International* 33, 91–95; 2000.
30. Guerrero L, Guàrdia MD. La medida de las propiedades mecánicas en la carne y en los derivados cárnicos. *Eurocarne* 77, 41–49; 1999.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

31. Virgili R, Parolari G, Schovazappa C, Soresi Bordini C, Borri M. Sensory and texture quality of dry-cured ham as affected by endogenous cathepsin B activity and muscle composition. *Journal Food Science* 60, 1183–1186; 1995.
32. García-Garrido JA, Quiles-Zafra R, Tapiador J, Luque de Castro MD. Activity of cathepsins B, D, H and L Spanish dry-cured hamo f normal and defective textura. *Meat Science* 56, 1–6; 2000.
33. Fernández X, Gilbert S, Vendeuvre JL. Effects of halothane genotype and pre-slaughter on pig meat quality. Part 2. Physico-chemical traits of cured-cooked ham and sensory traits of cured-cooked and dry-cured hams. *Meat Science* 62, 439–446; 2002.
34. Aalhus JL, Jones SDM, Tong AKW, Jeremiah LE. The combined effects of time on feed, electrical stimulation and aging on beef quality. *Canadian Journal of Animal Science* 72, 525–535; 1992.
35. Panea B, Mons´n A, Olleta JL, Martínez-Cerezo S, Pardos JJ, Sañudo C. Estudio textural de la carne de vacuno. II. Análisis sensory. Textura study of bovine meta. II. Sensory analysis. *Información Técnico-Económica Agraria* 24, 31–33; 2003.
36. Kilcast D. Force/deformation techniques for measuring texture. In: Kilcast D. *Texture in Food*. Cambridge: Woodhead Publishing Ltd; 2004, 109–145.
37. Sastre CM, Domínguez BM, Fernández CG. Tipificación de la Cecina de León: características físico-químicas, nutricionales y sensoryes. Instituto Tecnológico Agrario de Castilla y León; 2006, 110.
38. Szczesniak AS. Classification of textural characteristics. *Journal of Food Science* 28, 385–389; 1963.
39. Bourne MC. Textura profile analysis. *Food Technology* 32, 62–72; 1978.
40. Breene WM. Applications of texture profile analysis to instrumental food texture evaluation. *Journal Texture Study* 6, 53–82; 1975.
41. Hoz L, D´Arrigo M, Cambero I, Ordóñez JA. Development of a n-3 fatty acid and α-tocopherol enriched dry fermented saudage. *Meat Science* 67, 485–495; 2004.
42. Visesssanguan W, Soottawat B, Riebroy S, Thepkasikul P. Changes in composition and functional properties of proteins and their contributions to Nham characteristics. *Meat Science* 66, 579–588; 2004.
43. Houben JH, Hooft BJ. Variations in product-related parameters during standardised manufacture of a semi-dry fermented sausage. *Meat Science* 69, 283–287; 2005.
44. Campos RML, Hierro E, Ordóñez JA, Bertol TM, Terra NN, Hoz L. Fatty acid and volatile compounds from salami manufactured with yerba mate (*Ilex paraguariensis*) extract and pork back fat and meat pigs fedo n diets with partial replacement of maize with rice bran. *Food Chemistry* 103, 1159–1167; 2007.
45. Willems MET, Purslow PP. Effect of postrigor sarcomere length on mechanical and structural characteristics of raw and heat-denature single porcine musclu fibers. *Journal of Texture Studies* 27, 217–233; 1996.
46. Christensen M, Young RD, Lawson MA, Larsen LM, Purslow PP. Effect of added μ-calpain and postmortem storage on the mechanical properties of bovine single muscle fibers extended to fracture. *Meat Science* 66, 105–112; 2003.
47. Lepetit J, Culioli J. Mechanical properties of meat. *Meat Science* 36, 203–237; 1994.
48. Christensen M, Purslow PP, Larsen LM. The effect of cooking temperature on mechanical properties of whole meat, single muscle fibers and perimysial connective tissue. *Meat Science* 55, 301–307; 2000.
49. Ahn DU. Production of volatiles from acid homopolymers by irradiation. *Journal of Food Science* 67, 2565–2570; 2002.
50. Nam KC, Ahn DU. Mechanisms of pink color formation in irradiated precooked turkey breast. *Journal of Food Science* 67, 600–607; 2002.
51. Ruiz de Huidoro F, Miguel E, Blázquez B, Onega, E. A comparison between two methods (Warner-Bratzler and texture profile anlysis) for testing either raw meta or cooked meat. *Meat Science* 69, 527–536; 2005.
52. Fisher C, Scott TR. *Flavores de los alimentos, biología e química*. Barcelona: Acribia; 2000.
53. Röthe M. *Introduction to Aroma Research*. Dordrecht: Kluwer Academic Publishing; 1988.
54. Dalton P, Doolittle N, Nagata H, Breslin PAS. The merging of the senses: integration of sbthreshold taste and smell. *Nature Neuroscience* 3, 431–432; 2000.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

55. Malnic B. O código dos aromas. *Ciência Hoje* 211, 14–15; 2004.
56. Arnau J, Monfort JM. El jamón curado: Tecnología y análisis de consumo. *Simposio Especial—44th International Congress of Meat Science and Technology*. Barcelona; 1998, 205.
57. Flores M, Grimm CC, Toldrá F, Spanier AM. Correlations of sensory and volatile compounds of Spanish "Serrano" dry-cured ham as a function of two processing times. *Journal of Agricultural and Food Chemistry* 45, 2178–2186; 1997.
58. Du M, Nam KC, Ahn DU. Cholesterol and lipid oxidation products in cooked meat as affected by raw-meat packaging and storage time. *Journal of Food Science* 66, 1396–1401; 2001.
59. Decker EA, Mei L. Antioxidant mechanisms and applications in muscle. *49th Proceedings of the Reciprocal Meat Conference* 49, 64–72; 1996.
60. Whitfield FB. Volatiles from interactions of Maillard reactions and lipids. *Critical Reviews in Food Science Nutrition* 31, 1–58; 1992.
61. Han D, McMillin KW, Golber JS, Bindner TD, Younathan MT, Marshall DL, Hart LT. Iron distribution in heated beef and chicken muscles. *Journal Food Science* 58, 697–700; 1993.
62. Stephen Elmore J, Mottram DS, Enser M, Wood JD. Effect of the polyunsaturated fatty acid composition of beed muscle on the profile of aroma volatiles. *Journal of Agricultural Food Chemistry* 47, 1619–1625; 1999.
63. Baek HH, Cadwallader KR. Aroma volatiles in cooked alligator meat. *Journal of Food Science* 62, 321–325; 1997.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

PROCESSED MEATS AND POULTRY

II

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 7

Color Characteristics of Meat and Poultry Processing

José Angel Pérez-Alvarez and Juana Fernández-López

Contents

7.1 General Aspects of Color 101
7.1.1 Color Attributes 102
7.1.1.1 Appearance 102
7.2 Practical Aspects of Meat Color Measurement 102
7.2.1 Color Physics 102
7.2.2 Meat Color 104
7.2.3 Color during Meat Processing 104
7.2.3.1 Slaughter 104
7.2.3.2 Aging 105
7.2.3.3 Fresh Meat Products 105
7.2.3.4 Dry-Cured Meat Products 106
7.2.3.5 Cooked Meat Products 109
7.2.3.6 Marinated Meat Products 110
7.3 Functional Foods 111
7.3.1 Additives 113
References 113

7.1 General Aspects of Color

Color can be defined as a subjective sensation resulting from a complex series of physiological, physical, chemical, and psychological responses to electromagnetic radiation at a wavelength between 400 and 700 nm [1].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

7.1.1 Color Attributes

Many color spaces (e.g., Munsell, Hunter, or CIELAB), color order systems, and color appearance models, such as the Munsell color system [2], are used for color specification. CIELAB [3], which is used for formulating color differences, and CIECAM02 [4], which is used for the specification of color appearance, use lightness, hue, and chroma to specify color attributes.

Hue, lightness, and chroma are the perceptive aspects of colors defined in color science [5], whereas color memory, color meaning, and color harmony are cognitive aspects of color [6]. Hue is the dominant factor in color emotions, whereas the meaning of a color comes mainly from its lightness and chroma and to a lesser extent from its hue.

CIELAB color space can be represented by CIELCH space (lightness: L*, chroma: C*, and hue: H*). The L*C* plane is divided by three emotion indices into six regions based on the dependence of "soft–hard," "warm–cool," and "light–dark" on L* and C*. Soft and warm colors are clearly lighter and correspond to colors with high lightness and high chroma. Colors in the low chroma and low lightness region are cool, hard, and dark. Colors with high lightness and low chroma feel cool and soft, while colors with high chroma and low lightness feel hard and warm. The responses vary from dark to light with the increase of lightness or chroma [7], but an inconvenience of both the CIELAB and CIELCH planes is their nonuniformity.

7.1.1.1 Appearance

The perception of color is a complex process in the human visual system. The majority of researchers consider that color preference is cultural and even completely individual, yet they also agree that the conformity between different people about the general cognitive characteristic of colors is considerable [8]. To describe the appearances of color, it is generally agreed that five perceptual dimensions, or attributes, are necessary: brightness, lightness, colorfulness, chroma, and hue [9–12]. For color reproduction, hue and the relative color attributes, chroma and lightness, are typically used for color specification.

7.2 Practical Aspects of Meat Color Measurement

From an objective point of view, meat color is the result of an interaction of four factors: the light falling on the meat or meat product; the object (meat or meat product) that reflects or absorbs the light; the observer, and the surroundings [13].

7.2.1 Color Physics

Important tools in the study of color are the reflection spectra that represent the spatial distribution of radiation bands and that are obtained by separating the monochromatic components, thus permitting the composition of the whole band to be understood.

Reflectance spectroscopy is a major remote-sensing technique used to study the chemical composition and microstructure of various light-scattering media [14]. The reflected light spectrum is measured and used to decode the relevant information with respect to the inherent properties of a food layer in the framework of the radioactive transfer theory [15].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

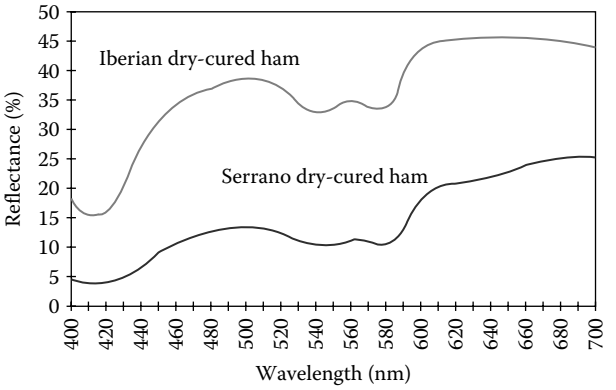


Figure 7.1 Reflectance spectra (400–700 nm) of Serrano and Iberian dry-cured ham.

In many cases, the scattering measured in foods depends on the optical thickness, and so on the food geometry, creating a problem if one is interested in the bidirectional reflectance determined by illumination and viewing angles. Optical phenomenon occurring at the air–food interface are of great importance in the field of food optics. Surface reflection can be used for color matching [15].

Color can be determined objectively by reflectance spectrophotometry both of the primary materials used in the industry [16–21], as can be seen in Figure 7.1, and of meat products derived [22–26]. Each of the primary materials has its own particular absorption and reflection spectrum [1,27]. Moreover, each of the states of myoglobin (Mb) can be quantified spectrophotometrically; for example, the maximum absorption of Mb and metmyoglobin (MetMb) are at 555 and 505 nm, respectively. The use of this technique permits measurements to be made of the product's surface without destroying the sample, and permits such measurements to be made as time elapses [28].

For the same reasons, this technique can be used to control the quality of the materials used in the elaboration of meat products.

Color measurement is dependent on the size of the port used to observe the samples, also known as the aperture size [29]. The same author [29] also found that the 10-mm aperture gives lower L*, a* (redness), and b* (yellowness) values (darker, less red, and less yellow) than the 50-mm aperture size. When the smaller aperture size is used, the reflectance values from the longer, red wavelengths in the visual range are reduced by a greater percentage than the shorter wavelengths (blue).

Sánchez-Rodríguez [30] reported that in Iberian dry-cured ham from pig fed with acorn L*, a*, b* and chroma showed metamerism by illuminant (C and D_{65}) both in the CIELAB and in HunterLab space for *Biceps femoris* (BF), *semitendinosus* (ST), and *semimembranosus* (SM) muscles. The same author found that observer metamerism occurred for lightness and yellowness for the same color spaces and illuminants.

For Karamucki et al. [31], L*, b*, and C* values in porcine *Longissimus lumborum* muscle were closely connected with meat quality. Meanwhile, redness and hue values showed medium and low correlations with meat quality traits. The application of illuminant D_{65} and an observer angle of 10°6 for measurements of meat color proved to be more suitable in the case of a* and C* parameters, whereas the use of illuminant C and observer an observer angle of 2° was more suitable in

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

the case of the hue angle (h°) parameter. For chicken and beef color, Zhu and Brewer [32] reported that a*, h°, and reflectances differences (R630–R580) could be used to predict visual redness under halogen light and cool white fluorescent light.

7.2.2 Meat Color

Meat color, primarily due to the presence of Mb, is an important characteristic in the consumer acceptance of meat products. However, color may vary greatly in fresh and processed products, and is strongly influenced by handling during storage and display [33]. Color development depends on methods used in manufacture as well as on the nitrosation of meat pigments [34].

Several color measurements are applied to meat; for example, Sahoo et al. used high Lovibond tintometer red color units and chroma, together with the MetMb content [35], but meat color researchers generally use CIELAB, and in some countries, such as Spain, this color space is used as official standard [1].

Some coordinates have been used as a tool for quality control. Schivazappa and coworkers correlated the color assessed by sensory evaluation with the a* value and (K/S572)/(K/S525) ratio, whereas Santamaria et al. [34] used spectrophotometric measurements of the nitrosation index (at R560/R500 nm) and the red color stability index (RI; at R570/R650 nm).

7.2.3 Color during Meat Processing

During meat and meat product processing, color may be very difficult to define in a single way, because several factors (chemical, physical, biochemical, and microbiological, among others) and complex reactions are interrelated [19].

The techniques of mincing, mixing, cooking, and drying, together with the incorporation of additives and spices, all have an effect on color. Such processes are common in the production of meat products and play a fundamental role in the development of the essential characteristics of each product. Although these are very common operations, they are, from a theoretical point of view, quite complex and no complete description exists regarding their influence on color.

7.2.3.1 Slaughter

In fresh meat, such factors as the interaction of the slaughter process and animal stress or exhaustion can result in massive variation in meat appearance. This is usually a direct consequence of differences in the rate and extent of the pH fall that occurs after slaughter coupled with the speed of carcass chilling and the length of aging. Colors that would normally be an attractive bright red-pink may appear dark jelly-like translucent purple or pale opaque pink due to the light scattering properties of the meat. This greater than twofold range in the scattering power of the product leads to unacceptable quality variations both in color and texture [36].

The energy status of the chicken at slaughter has a large impact on the development of postmortem pH and hence color. Nisen and Young [37] found that creatine monohydrate and glucose supplementation to slow- and fast-growing chickens had no effect on these parameters. In ostriches, Fasone et al. [38] reported that meat lightness was strongly affected by stress, the color of meat from the "stress group" being darker than the meat from the "non-stressed group" (L*: 34.30 and 38.10, respectively). The other color parameters were not affected by stress.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Bianchi et al. [39] reported that holding time and temperature exerted the most important effect on broiler breast meat color. However, other factors, such as genotype, live weight, and transportation, may influence breast meat color. These authors also reported that market live weight influenced color parameters; for example, the heavier birds (>3.3 kg) produced a darker breast meat ($L^* = 51.67$) than did the lighter birds (<3.0–3.3 kg; $L^* = 52.63$). When the birds were transported for distances of <40 km, the breast meat color exhibited higher redness (a*: 3.59), whereas for longer distances a* diminished.

Linares et al. [40], in their study of how stunning systems affect the color of lamb meat, found that the animals slaughtered after CO_2 stunning showed lower redness and yellowness values than control groups (without previous stunning).

After slaughter, food inspectors and veterinarians use the color of livers to tell whether this offal is suitable for human consumption. It is also possible to approximately determine whether liver has a high or low amount of hepatic lipids. Thus, lighter liver colors in full-fed broilers were associated with higher hepatic lipid concentrations; in contrast, darker livers from fasted broilers had lower levels of lipids [41].

For processing purposes, chicken color can be classified on the basis of lightness values as dark ($L^* < 50$), normal ($50 \leq L^* \leq 56$), or pale ($L^* > 56$) according to Petracci et al. [42]. These authors also reported that paler ($L^* > 56$) chicken breast meat is associated with lower ultimate pH and lower water-holding capacity (WHC), whereas darker ($L^* < 50$) chicken breast meat is associated with higher pH and cooking yield. In beef, meat color values decrease with increasing pH, and increase with increasing backfat thickness [43]. Dvorak et al. [44] reported that a* (redness) was the most important aspect of color for objective pork quality evaluation on a production line in a large slaughterhouse, although this coordinate showed a very low correlation coefficient for pH and drip loss.

7.2.3.2 Aging

Aging is a common practice in meat production and plays an important role in several quality characteristics, such as texture and color. With regards to color, aging improves blooming, and Lindahl et al. reported that aging increased the oxymyoglobin (OMb) content of pork *Longissimus dorsi* muscle and the decreased content of deoxyMb, resulting in increased lightness, redness, and yellowness. Also, aging has a smaller effect on color stability, with slightly lower MetMb being observed in aged meat [45]. In other studies, the aging of pork loins increased lightness and slightly increased yellowness; tenderness was also improved [46]. In beef, aging has a marked influence on all color parameters [47]. The maturity of the carcass increases the redness and lightness of meat and the yellowness of fat [48]. In *Longissimus dorsi* muscle, the chilling rate affects lightness, yellowness, and h° differences, whereas fat cover thickness affects the influence that aging has on lightness and yellowness [47]. In Rubia Gallega (RG) breed aging, meat color increased redness, yellowness, hue, and chroma [49], but Oliete et al. [50,51] reported that pigment concentration decreased with aging time. In the RG breed, color variables were the most determinant characteristic of meat quality.

7.2.3.3 Fresh Meat Products

Several studies have pointed to the importance of the different states of Mb in determining the color changes that take place during processing [19]. In fresh pork lean meat, color parameters

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

(L*, a*, b*, h°, C*, and a*/b* ratio), reflectance spectrum (400–700 nm), and reflectance ratios (R560/R500, R650/R570, R630/R580, and R630-R580) varied according to the state of the Mb.

Biochemical aspects, such as lactate dehydrogenase (LDH) activity, was negatively correlated with the Mb content of muscle tissue. LDH activity (%) in the sarcoplasmic fraction is higher in porcine than in bovine muscle, and this can affect the color of meat products manufactured with these meats [52].

During the storage of fresh sausages, products change to a brown color, a change related to MetMb formation. Schivazappa et al. [53] described that the brightest red color is only stable for up to 7 days when the sausages are packaged under atmospheres containing O_2, although this period can be increased if the product is packaged under an O_2-free atmosphere. The bright red color (OMb) in pork sausages is related to the presence of oxygen in the pack atmosphere; but when it decreases (after 7 days), the pigment changes mainly to MetMb. These authors found a correlation between Mb oxidation and lipid oxidation.

Fresh meat and meat products are normally exposed in a light box or in a supermarket display case. The sample is illuminated from both above and from the sides. In fresh meat, such factors as the interaction of the slaughter process and animal stress or exhaustion can result in massive variation in meat appearance [54].

The addition of potassium lactate (KL) improved the microbial counts of patties, with no effect on color or lipid oxidation. But when this additive was added to chunks, color stability increased and microbial counts decreased [55]. KL stabilizes postmortem muscle color via the interaction of KL with lactic dehydrogenase to regenerate reducing equivalents (nicotinamide adenine dinucleotide), which subsequently increases MetMb-reducing activity [56,57]. Most pigment oxidation occurs when meat is exposed to light (decreasing a*, b*, and C*), but KL can help protect against the negative influence of light, via the mechanism described by Seyfert et al. [58].

7.2.3.4 Dry-Cured Meat Products

Dry-cured meat products can be described from a technological point of view as products that, during their elaboration, are treated at controlled temperature and humidity for variable times both to favor microbiota development and for dehydration. During this process, a complex series of chemical, enzymatic, and ultrastructural reactions takes place, together with different physical processes, which modify the properties of the product [1].

7.2.3.4.1 Dry-Cured Sausages

The manufacturing process of these dry-cured meat products consists of four basic stages: mincing, mixing, fermentation, and dry-maturation [54].

In the first step, the raw materials are reduced in size and mixed with additives and spices to make a batter, which is generally left to rest for 12–24 h (depending on the type of product). The meat batter is then stuffed into a casing, before being allowed to ferment and mature.

Color formation in dry-cured meat products takes place during the different stages of elaboration in response to biochemical mechanisms related to the characteristics of the materials used, the technological operations applied, and the additives or spices incorporated.

During the manufacture of dry-cured sausages the pH falls as a consequence of the metabolic activity of the microorganisms present [1]. The extent to which light rays penetrate or are reflected depends on the pH, so that dispersion increases as pH falls [59].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

In studies investigating such changes in dry-cured pork products, variations in the color coordinates have been observed to take place during the resting stage [60].

In the case of dry-cured sausages, and from a strictly color point of view, this will depend on such diverse factors as the composition of the sausage, the fat–lean ratio, salt content [61], curing salts used, the presence of organic acids, the proportion and type of spices, other additives (polyphosphates, sugars, etc.), the technological treatments applied (e.g., the degree of mincing, mixing time, or fermentation time), dry-maturation, type of animal meat, the composition (content and distribution of fat and muscle fraction), technological treatment applied, the different phenomena that occur during the elaboration process, and storage (since this type of product undergoes different physical, chemical, biochemical, and ultrastructural transformations), all of which modify the color of the final product. Reactions such as the formation of nitrosomyoglobin (NOMb), a characteristic pigment of this type of product, the availability of water on the product surface, degree of integrity of the muscle tissue, and the state of the ultrastructure, are phenomena to be taken into account when evaluating the color of this type of product [62].

Chasco et al. [63] reported that nitrites react with Mb to form NOMb and MetMb during the fermentation stage; this MetMb is subsequently reduced to NOMb during the drying process. But the main color changes of Spanish dry-cured sausages took place during the fermentation stage [25,60,64]. Pérez-Alvarez [1] established that the color evolution (CIELAB) in dry-cured meat products (low fermentation temperature, fermented sausages, with and without paprika addition, and whole dry-cured meat cuts such as dry-cured loin and dry-cured ham) was lightness, yellowness, hue, and chroma decreasing, and redness and a*/b* ratio increasing. This behavior can be observed in Figure 7.2. For Sucuk, Turkish sausage color parameters changed during the dry-curing processing; thus, lightness, yellowness, and h° decreased during the ripening period. For this meat product, Bozkurt and Bayram [65] found that the main color changes take place between the fifth and ninth days of the ripening period. These authors also found a positive relationship between redness and sensory color scores.

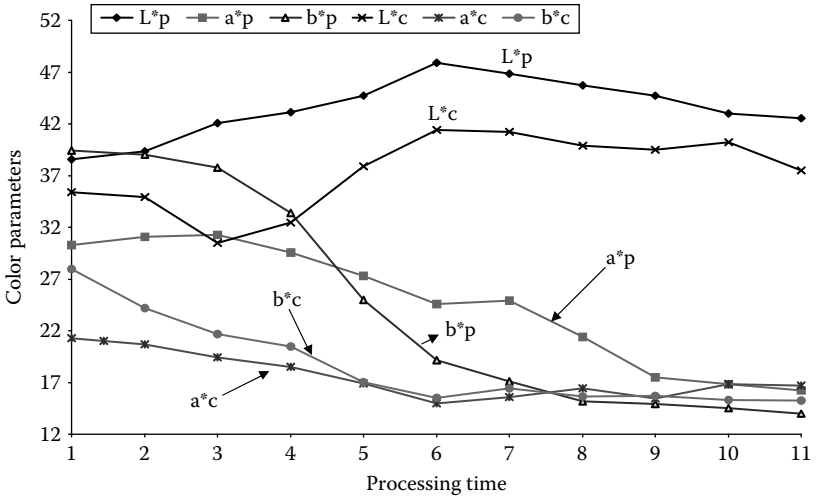


Figure 7.2 CIELAB color coordinates evolution during paprika oxidation under ultraviolet light exposure and dry-cured sausage added with paprika (chorizo) elaboration process. L*, lightness; a*, redness; b*, yellowness; p, paprika, and c, chorizo.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

7.2.3.4.1.1 Paprika The addition of paprika to meat products has been observed to modify color coordinates in several ways. For example, its addition reduced L* [54,62], whereas a* and b* values of meat increased. The meat color itself was masked by paprika [66]. Paprika also affects reflectance spectra, regardless of the meat product or processing conditions. The color modifications observed in dry-cured meat products containing paprika are due principally to changes that occur in the paprika, as opposed to changes in meat color itself, as can be seen in Figure 7.2.

7.2.3.4.1.2 Starter Cultures Several studies dating from the 1950s have shown that the use of starter cultures improves the color of meat products. However, recent studies have described a new type of bacteria used in meat products, and Khankhalayaeva et al. [67], for example, showed that propionic acid bacteria increase the formation of nitrous pigments and stabilize the color of meat products. They also mentioned that the use of sodium nitrite can be reduced (30%) without reducing the final color of the same products. When *Staphylococcus carnosus* and *S. xylosus* were added to Chinese-style sausage, they improved the color stability of this sausage [68]. At the same time, it is important to mention that these starter cultures in this sausage showed higher concentrations of nitrosyl-pigments and lower MetMb contents. Inoculated sausages showed higher redness values than control samples, whereas L* and b* decreased during processing.

According to Moller et al. [69] *Lactobacillus fermentum* strains (JCM1173 and IFO3956) and *Pediococcus pentosaceus* PC-1 and *S. carnosus* XII can generate nitrosylated derivatives from Mb. All of these bacteria can convert brown MetMb into red OMb, but only the lactobacilli can specifically produce nitrosylmyoglobin, especially in smoked fermented sausages.

Vural [70] reported that *P. acidilactici* can be used as starter culture for a Turkish semidry-fermented sausage. This culture increases the conversion of heme pigments to cured meat pigments and improves the development of the typical Turkish sausage color.

7.2.3.4.2 Dry-Cured Ham

In this type of meat product, salt diffusion plays an important role in the development of color. Thus, when salt diffuses through meat, the color coordinates change. This is related to changes in the WHC and interconversion of Mb states. But when the WHC does not change during maturation, such color changes are related to ultrastructural disorganization and modification of the Mb structure. There is a gradient of color coordinates in this type of product, and each muscle has different color parameters, according to its anatomical distribution. Indeed, in the same muscle, it is possible to obtain a color gradient due to salt diffusion and ultrastructural disorganization of the muscular structure [71]. At the end of the aging step ("afinado") of Serrano dry-cured ham, the most important muscles, such as SM, ST, and BF, showed different color values: SM showed the lowest values of the color parameters, except for the a*/b* ratio; BF had the highest values, except for the a*/b* ratio. BF and ST showed similar values for redness, yellowness, and hue. This author also obtained a correlation between L* and the moisture content and water activities [26]. From a sensorial point of view, Sánchez-Rodríguez [30] reported that "veteado" (intramuscular fat) of Guijuelo acorn-fed Iberian dry-cured ham reduces the red meat color and contributes to the "brilliance" of the cut surface.

7.2.3.4.2.1 Parma and Iberian Dry-Cured Ham Pigments The stable, bright red color of some dry-cured hams, such as Parma ham, is achieved without the need for added nitrate or

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

nitrite [72]. In dry-cured hams, Moller et al. [73] observed the presence of chemically identical red chromophores with properties similar to a complex of transition metals and protoporphyrin IX (Zn–porphyrin complex). Similar findings in Parma ham were obtained by Wakamatsu et al. [74].

The substitution of iron by zinc in Mb structure during the maturation of Parma ham is concomitant with Mb modifications [75]. These changes begin during the resting period following salting and seem to precede the formation of zinc porphyrin. Electron spin resonance spectra showed that the pigment in dry-cured Parma ham is at no stage a nitrosyl complex of ferrous Mb, as found in brine-cured ham and Spanish Serrano hams [76]. Protein denaturation/degradation facilitates the substitution of iron by zinc, but pigment polymerization may also be the result of noncovalent protein association with zinc porphyrin in denatured or partly degraded Mb [75].

Parma ham increases its lipophilic character during processing, suggesting that a combination of drying and maturing yields a stable red color [77].

At the end of processing, pigments become less extractable with water. The heme moiety of Parma ham pigment is gradually transformed from a Mb derivative into a nonprotein heme complex, thermally stable in an acetone/water solution [76].

The Zn–porphyrin complex has better color stability than those pigments from dry-cured ham with added nitrites. This Zn–porphyrin complex showed faster initial discoloration when exposed to light, under retail conditions [78]. Thus, Adamsen et al. [79] found that apomyoglobin did not show antioxidative capacity, although the heme moieties had antioxidative properties. These authors also found that lipid oxidation was inhibited by the addition of Parma ham pigment (0.12–0.24 ppm), and that this Zn–porphyrin complex can protect alpha-tocopherol degradation.

Spectral patterns from Parma ham differed from those of the Mb derivatives [80]. Among other hypotheses proposed, some authors have suggested that the reddening of Parma ham is probably caused by the action of bacteria; the *Staphylococci* isolated from Parma ham also generate the red Mb derivative from MetMb.

In other dry-cured meat products, the use of nitrite inhibits the reduction of heme pigments in meat products in the presence of NaCl [81].

7.2.3.5 Cooked Meat Products

Fernández-Ginés et al. [82] established the pattern of color formation during the whole cooking process, lightness, and yellowness decreasing but redness increasing during heat treatment. These authors reported that color changes are related to changes into internal temperature and the state of the sarcoplasmic pigments. Also, the color characteristics of the batter were closely related to the degree of pigment nitrosation, and the redness of the batter may be used as an index for assessing the mincing process. It must also be taken into account that the color of freshly minced batters is closely related to the color of the final products [83].

In a model system, Sakata and Nagata found that low molecular weight of the sarcoplasmic fraction of *Longissimus thoracis* muscle, in combination with preheating Mb, enhanced cured color formation during the subsequent reaction with nitrite. Studies with pork sausage indicated that denaturation and the nitrosation of heme pigments followed a similar pattern. Sakata and Nagata suggested that this behavior might be due to the acceleration of the heat denaturation of heme pigments, resulting in their rapid nitrosation [82,84].

The addition of polyunsaturated fatty acids to animal diets, for example, the use of rich linoleic acid feeds, may produce several problems during the cooking process of this meat. Bergamaschi

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

et al. [85] found that a high level of linoleic acid favored an increase in rancidity and color oxidation in muscles liable to oxidation, such as *masseter*, but had no significant effect on glycolytic-type muscles (shoulder). But when mortadella bologna was elaborated with these muscles, an unacceptable color was sometimes observed after cooking, accompanied by an increase in rancidity.

When diphosphate is added to sausages, the development of NOMb is not affected; the color of the sausages was only slightly less red than control sausages when this additive was used with ascorbate. It is very interesting to note that the addition of diphosphate increased the cured color of sausages [86], whereas the residual nitrite concentration decreased.

Several attempts have been made to obtain natural colorants from blood, and to apply this to meat products, especially cooked meat products. For example, Ito et al. [87] used the electrolytic reduction of heme protein (MetMb and methemoglobin) solutions, and found a stable nitrosyl derivative by means of limited electrolysis in the presence of sodium ascorbate and nitrite, at neutral pH values, especially in the presence of 1 M sucrose. When these electrolytically obtained pigments were used in meat products (sausages), their redness increased.

Blood derivatives are used as ingredients in cooked meat products [88]. The red cell fraction of slaughtered cattle blood is treated to obtain nitrosated hemoglobin for use as a colorant in cooked meat products. This nitrosohemoglobin improved the color of sausages [88]; the color remained stable for 2 weeks at 2°C and no differences were detected, but redness retention was better than for control samples. When this colorant was applied to pork sausages (0.5 or 1%), redness increased [89]. Krysztofiak [90] described how the use of plasma proteins negatively affected the color of the cooked meat products (sausages) in which they were incorporated. In general, discoloration (brown color) in meat occurs when L* and b* values increase, and a* values decrease. Other new techniques have been used to improve the healthy appearance of meat products; for example, Kwon [91] used supercritical carbon dioxide to produce meat with a low fat concentration, and found that this technique produced meat with a lighter color. If this meat is used for meat products, the product is also lighter than control products.

If exposed to light, the redness of cooked meat products diminishes during storage. This phenomenon, in pork bologna, is related more with photochemical than thermal processes, and the action of temperature on color was attributed by Carballo et al. [92] to microbial growth, which in turn affects oxygen availability. Turkey bologna color is modified by light during retailing, the extent of its color fading depending on increases in yellowness, rather than decreases in redness [93].

Deep fat frying of beef meat balls affects the kinetics of surface color [94]; thus, surface colors (L*, a*, and b*) decrease exponentially with frying time, whereas total color change increases. During this process, color evolution follows first-order reaction kinetics.

Redness in cooked ham is the most sensitive parameter in color measurement, characterizing red color and color stability [95]. In this product, consumers prefer a lighter color and less redness (higher value of L* and a lower *a**), a deeper red color suggesting the addition of artificial coloring. Válková et al. [96] reported that the color characteristics for cooked ham ranged from 61.57 to 68.97 L* value (lightness), 8.14–13.95 a* value (redness), and 6.60–9.70 b* value (yellowness).

7.2.3.6 Marinated Meat Products

As other technologies, marination can affect color. In this technique the additives used in the bath modify color co-ordinates. For example, the use of sodium tripolyphosphate dicalcium hydrogen

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

phosphate solution modified lightness, but when citric acid was used, yellowness increased [97]. Pérez-Alvarez and Fernández-López [13] suggest that most of the phosphates used in meat processing decrease lightness because of their influence on WHC and acid ingredients.

The use of phosphates in marinated cooked broiler leg muscles did not affect color parameters, except that yellowness increased [98].

7.3 Functional Foods

Since the 1980s, the scientific–technological advances made in the food industry relating food with health have given rise to a new sector in the world of food technology known as "functional foods" [99]. According to Fernández-Ginés et al. [100], the meat sector in recent years has been one of the most dynamic in the agro-food field, because it has rapidly incorporated functional foods into its repertoire, using a wide variety of new ingredients with the aim of making healthier meat products.

From a technological and scientific point of view, many food ingredients have been shown to play a beneficial role in health [101], improving the physiological functions of the human organism and permitting the design and optimization of foods that prevent or diminish the risk of certain chronic diseases [102]. However, from the consumer's point of view, it is very important for functional meat products to possess almost the same sensory characteristics as similar or traditional meat products [100], in which color plays an important role. However, one of the inconveniences associated with the incorporation of new ingredients in any food, and meat products are not the exception, is the effect that this might have on the corresponding technological, nutritional, and sensory properties. Some ingredients or bioactive compounds may produce undesirable colors. This is particularly problematic in the case of dry-cured sausages [103,104], to which botanical and herbal ingredients (depending on the region or country) are frequently added [105].

Along with botanical or herbal additives, increased protein levels and vitamin and mineral fortification can lead to unacceptable flavors and marked alterations in the product's color [1]. It must also be taken into account that the concentration of added ingredients can disrupt the normal evolution (chemical, biochemical, enzymatic, etc.) of these types of meat product, especially dry-cured products [106]. Ingredients such as polyphenols can act as antioxidants (in low doses) [107] or prooxidants (in high doses) [108], and, as is known, the color stability of dry-cured meat products is related to lipid oxidation:

Plum fiber. In meats, dried plum purée has moved beyond functioning as a fat replacer. It has been used in frozen, precooked meats (such as precooked hamburgers). Plum purée is used in meat between 3 and 5%. In pale-colored applications, the 3% level improves the end result, taking some of the pinkish color out of poultry [109,110].

Apple fiber. It is used in the elaboration of reduced-fat cooked meat sausages (mortadella). Color differences observed between sausages were mainly due to reduction because the addition of fiber slightly modified the color of the sausages, making them more yellow than the control sausages [111].

Citrus fiber. Citrus albedo (raw and cooked) added to cooked and dry-cured sausages produced significantly lower residual nitrite levels (higher with raw than cooked albedo) [103,104,112,113]. Yellowness was the only color parameter not affected by albedo type

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and concentration in both types of sausages. In bolognas, lightness increased when albedo was added, and this increase was higher when raw albedo was added rather than cooked albedo. These results mean that the albedo addition gave a lighter-colored product. On the contrary, when albedo was added to dry-cured sausages, lightness values decreased, especially in the case of cooked albedo. Albedo affected redness in a different way, depending on the type of sausage, increasing in dry-cured sausages and decreasing in cooked sausages.

When lemon albedo was added to the drying step of dry-cured sausage processing, color evolution was not affected by the presence of albedo. However, CIELAB color parameters L* and b* decreased, whereas a* increased during drying. According to Fernández-Ginés et al. [114], citrus fiber extract up to 25 g/kg affects color properties, mainly a* and b*, which increase independently of citrus fiber addition. These authors also found that this type of fiber can act as nitrite scavenger, which was also observed by Aleson-Carbonell et al. [103,104] in several meat products. Garcia et al. [115] manufactured conventional and low-fat cooked sausages (mortadella type) with fruit fiber (15 and 30 g/kg) and reported that the fiber only increased yellowness.

Pea fiber and soy protein. These effectively protected the product against surface oxidation. The addition of pea fiber improved color stability of ground beef, although soy protein gave the best protection against the auto-oxidation of red OMb to brown MetMb. The addition of soy protein concentrate mixed with κ-carrageenan (0–3%) [116] favorably affected the WHC and thermal stability of the processed sausages regardless of the fat content, but did not improve the textural parameters, and no significant influence on color parameters was observed.

Rice bran. This has been used as an ingredient in frozen sausages [117], resulting in products showing a higher tendency toward red.

Rye bran. This has been used as a fat substitute in the production of meatballs. Its incorporation produces a lighter and yellower product than the control [118].

Olive oil. This has been used as a fat replacer in fermented sausages, the resulting products being lighter in color and more yellow [119].

Interesterified vegetable oils. Interesterified vegetable oils (60–100%) in meat products led to a significant increase in the oleic and linoleic acid content of meat products and a higher polyunsaturated fatty acids (PUFA)/saturated fatty acids (SFA) ratio, without any change in appearance, including color [120].

Conjugated linoleic acid. Conjugated linoleic acid as fat substitute improved the color stability, possibly by inhibition of lipid oxidation and OMb oxidation [121].

Lycopene. In meat products such as minced meat, the addition of lycopene from natural sources produces a meat product with better color and a well-documented health benefit [122].

Some of the new functional ingredients have color in themselves, which, in many cases can act as colorants, changing reflectance spectra and the color characteristics of a dry-cured sausage and of other meat products. Ruíz-Cano et al. [123] reported that orange fiber extracts (OFE) as a "functional ingredient" did not modify the sausage meat batter reflectance spectrum (Figure 7.3), and found the highest reflectance values in the orange and red wavelengths. This was correlated with higher redness values in the meat products.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

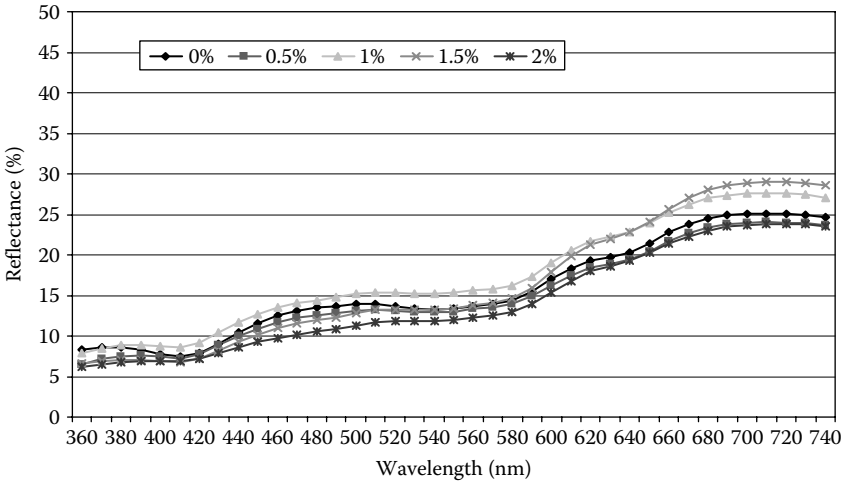


Figure 7.3 Reflectance spectra (360–740 nm) of a dry-cured sausage added with different concentrations of OFEs at time 28 days.

7.3.1 Additives

Salt replacers in meat products can affect the color of the product. For example, a mixture of NaCl, KCl, $MgCl_2$, and $CaCl_2$ (1.00, 0.55, 0.23, and 0.46%, respectively) was used in dry fermented sausage to replace NaCl alone [124]. Gimeno et al. [124] reported that these salt replacers decreased the micrococcaceae and nitrosoheme pigments. Ibanez et al. [125] reported that the replacement of NaCl by KCl in dry-cured sausages, using *L. plantarum* and *S. carnosus* as starter culture, led to a faster and more intensive nitrosation process than when NaCl was used alone. The chemical conversion of heme pigment percentages (nitrosopigments/total pigments × 100) were higher in the sausages made with NaCl + KCl during the whole ripening process. Also, the RI was higher, indicating that less oxidation of heme pigments occurred when this salt mixture was used.

To improve the health benefits of restructured meat products, new ingredients are now incorporated. Thus, Cofrades et al. [126] added walnuts, which provoked changes in the color coordinates (lightness decreased, whereas redness and yellowness increased). Koo et al. [127] added enoki mushroom; the redness and yellowness of a fish meat paste increased and the product was darker. When palm fats (palm oil and palm olein) were added to chicken frankfurters, the color significantly changed in all the coordinates [128].

References

1. Pérez-Alvarez, J.A. Contribución al estudio objetivo del color en productos cárnicos crudo-curados (PhD Thesis). Valencia, Spain: Universidad Politécnica de Valencia, 1996.
2. Nickerson, D. History of the Munsell color system and its scientific application. *J Opt Soc Am* 30: 575–580, 1940.
3. Commission Internationale de l'E´clairage (CIE). Colorimetry. *CIE Pub* 15.2, pp. 20–33, 1986.
4. Commission Internationale de l'E´clairage (CIE). A colour appearance model for colour management systems: CIECAM02. *CIE Pub* 159, 2004.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

5. Commission Internationale de l'E´clairage (CIE). International Lighting Vocabulary, *CIE Pub* 17.4, pp. 15–24, 1987.
6. Yendrikhovskij, S.N., F.J.J. Blommaert and H. De Ridder. Representation of memory prototype for an object color. *Color Res Appl* 24: 393–410, 1999.
7. Xiao-Ping, G. and J.H. Xin. Investigation of human's emotional responses on colors. *Color Res Appl* 31: 411–417, 2006.
8. Hardin, C.L. and L. Maffi. *Color Categories in Thought and Language*. Cambridge, United Kingdom: Cambridge University Press, 1997.
9. Fairchild, M.D. *Color Appearance Models*. New York: Wiley, 2005.
10. Wyszecki, G. and W.S. Stiles. *Color Science: Concepts and Methods, Quantitative Data and Formulae*. New York: Wiley, 1982.
11. Mausfeld, R. Color perception: from Grassmann codes to a dual code for object and illumination colors. In *Color Vision: Perspectives from Different Disciplines,* W.G.K. Backhaus, R. Kliegl and J.S. Werner (eds.) New York: Walter de Gruyter, 1998.
12. Berns, R.S. *Billmeyer and Saltzman's Principles of Color Technology*. New York: Wiley, 2000.
13. Pérez-Alvarez, J.A. and J. Fernández-López. *Aspectos físicos, fisiológicos, psicológicos, químicos e instrumentales para la determinación del color en los alimentos*. Alicante, Spain: Universidad Miguel Hernández, 2000.
14. Hapke, B. *Theory of Reflectance and Emittance Spectroscopy*. Cambridge, United Kingdom: Cambridge University Press, 1993.
15. Kokhanovsky, A. and L.G. Sokoletsky. Reflection of light from semi-infinite absorbing turbid media. Part 1: spherical albedo. *Color Res Appl* 31(6): 491–497, 2006.
16. Pagán, M.J. Caracterización de pimentones y estudio de la influencia de éstos sobre las propiedades del chorizo (PhD Thesis). Valencia, Spain: Universidad Politécnica de Valencia, 1998.
17. Pérez-Alvarez, J.A. et al. Utilización de vísceras como materias primas en la elaboración de productos cárnicos: güeña. *Alimentaria* 291: 63–70, 1998.
18. Pérez-Alvarez, J.A. et al. Caracterización de los parámetros de color de diferentes materias primas usadas en la industria cárnica. *Eurocarne* 63: 115–122, 1998.
19. Fernández-López, J. et al. Characterization of the different states of myoglobin in pork meat using colour parameters and reflectance ratios. *J Muscle Foods* 11: 57–68, 2000.
20. Navarro, C. et al. Characterization of three commercial categories of ostrich meat by colour parameters. *Eurocarne* 89: 93–99, 2000.
21. Pérez-Alvarez, J.A., J. Fernández-López, and M.E. Sayas-Barberá. Fundamentos físicos, químicos, ultraestructurales y tecnológicos en el color de la carne. In *Nuevas Tendencias en la Tecnología e Higiene de la Industria Cárnica*, M.R. Rosmini, J.A. Pérez-Alvarez and J. Fernández-López (eds.), pp. 51–71. Elche: Universidad Miguel Hernández, 2000.
22. Sánchez-Rodríguez, E., V. Aranda and A. Gago-Gago. Evolución de los parámetros de color durante el proceso de elaboración del lomo embuchado. In *Anales de Investigación del Master en Ciencia e Ingeniería de Alimentos*, P. Fito, J. Serra, E. Hernández and D. Vidal (eds.), pp. 690–703. Valencia, Spain: Servicio de Publicaciones de la Universidad Politécnica de Valencia, 1994.
23. Perlo, F. Caracterización física y fisicoquímica de pastas finas: Pat**é** (PhD Thesis). Valencia, Spain: Universidad Politécnica de Valencia, 1997.
24. Sayas-Barberá, E. et al. Caracterización física y fisicoquímica de la Longaniza Imperial de Lorca. *Alimentaria* 294: 27–33, 1998.
25. Pérez-Alvarez, J.A. et al. Physicochemical characteristics of Spanish type dry-cured sausage. *Food Res Int* 32: 599–613.
26. Pérez-Alvarez, J.A. et al. Chemical and color characteristics of Spanish dry-cured ham at the end of the aging process. *J Muscle Foods* 10(2): 195–201, 1999.
27. Fernández-López, J. Estudio objetivo del color en sistemas modelo de pastas de embutidos crudo-curados (PhD Thesis). Murcia, Spain: Universidad de Murcia, 1998.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

28. Hunt, M.C. et al. *Guidelines for Meat Color Evaluation*. Chicago: American Meat Science Association and National Live Stock and Meat Board, 1991.
29. Sterrenburg, P. Influence of sample illumination and viewing on the colour measurement of translucent materials like meat. In *Proceedings 35th International Congress of Meat Science and Technology*, pp. 610–613. Copenhagen, Denmark, Danish Meat Research Institute, 1989.
30. Sánchez-Rodríguez, E. Características químicas, fisicoquímicas y de color en el jamón ibérico de bellota denominación de origen (D.O.) Guijuelo (PhD Thesis). Salamanca, Spain: Universidad de Salamanca.
31. Karamucki, T. et al. Relationship between CIE L*a*b* and CIE L*C*h scale colour parameters determined when applying illuminant C and observer 2° and illuminant D_{65} and observer 10° and proximate chemical composition and quality traits of porcine longissimus lumborum muscle. *Polish J Food Nutr Sci* 15/56(2): 129–135, 2006.
32. Zhu, L.G. and M.S. Brewer. Relationship between instrumental and visual color in a raw, fresh beef and chicken model system. *J Muscle Foods* 10(2): 131–146, 1999.
33. Whang, K., Lee, S.P., Kim, H.Y. Colorimetric values of various myoglobin derivatives in pork and beef ribeye. *J Food Sci Nutr* 9(2): 183–186, 2004.
34. Santamaria, I. et al. Development of colour in Pamplona chorizo: reactions of nitrites, nitrates and meat pigments. *Alimentaria* 229: 23–26, 1992.
35. Sahoo, J., A.S.R. Anjaneyulu and A.K. Srivastava. Improvement in the quality of frozen ground buffalo meat by pre-blending with natural antioxidants and vacuum packaging. *J Food Sci Technol India* 35(3): 209–215, 1998.
36. MacDougall, D.M. Discontinuity, bubbles and translucence: major error factors in food colour measurement. In *9th Congress of International Colour Association*, SPIE, The International Society for Optical Engineering, pp. 268–269. New York: Rochester Institute of Science and Technology, 2001.
37. Nissen, P.M. and J.F. Young. Creatine monohydrate and glucose supplementation to slow- and fast-growing chickens changes the postmortem pH in *pectoralis major*. *Poultry Sci* 85(6): 1038–1044, 2006.
38. Fasone, V., A. Priolo and E. Carbajo. Effect of stress on ostrich meat quality. In *Proceedings of the 3rd International Ratite Science Symposium of the World's Poultry Science Association WPSA and 12th World Ostrich Congress*, E. Carbajo (ed.), pp. 393–396. Madrid, Spain: World Poultry Science Association (WPSA), 2005.
39. Bianchi, M., M. Petracci and C. Cavani. The influence of genotype, market live weight, transportation, and holding conditions prior to slaughter on broiler breast meat color. *Poultry Sci* 85(1): 123–128, 2006.
40. Linares, M.B., R. Bornez and H. Vergara. Effect of different stunning systems on meat quality of light lamb. *Meat Sci* 76(4): 675–681, 2007.
41. Trampel, D.W. et al. Preharvest feed withdrawal affects liver lipid and liver color in broiler chickens. *Poultry Sci* 84(1): 137–142, 2005.
42. Petracci, M. et al. Color variation and characterization of broiler breast meat during processing in Italy. *Poultry Sci* 83(12): 2086–2092, 2004.
43. Seok-Jung-Kim et al. Analysis of factors for seasonal meat color characteristics in Hanwoo (Korean cattle) beef using decision tree method. *J Animal Sci Technol* 44(5): 607–616, 2002.
44. Dvorak, P., H. Musilova, and I. Svarcova. On-line measurements of color of pork. *Fleischw Inter* 2: 89–91, 2001.
45. Lindahl, G. et al. Significance of storage time on degree of blooming and colour stability of pork loin from different crossbreeds. *Meat Sci* 72(4): 603–612, 2006.
46. Vautier, A. et al. Pork meat: extended ageing gives more tender meat. *Viandes et Produits Carnes* 24(6): 215–218, 229, 2005.
47. Boakye, K. and G.S. Mittal. Changes in colour of beef M. *Longissimus dorsi* muscle during ageing. *Meat Sci* 42(3): 347–354, 1996.
48. Moon, S.S. et al. The relationship of physiological maturity and marbling judged according to Korean grading system to meat quality traits of Hanwoo beef females. *Meat Sci* 74(3): 516–521, 2006.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

49. Oliete, B. et al. Study of rubia gallega breed veal quality during the ageing time under vacuum. *Archivos de Zootecnia* 55(209): 3–14, 2006.
50. Oliete, B. et al. Effect of weaning status and storage time under vacuum upon physical characteristics of meat of the rubia gallega breed. *Meat Sci* 73(1): 102–108, 2006.
51. Oliete, B. et al. Influence of ageing time on the quality of yearling calf meat under vacuum. *Eur Food Res Technol*, 220(5–6): 489–493, 2005.
52. Hamm, R. and A.A. El Badawi. Activity and subcellular distribution of lactate dehydrogenase in light and dark muscle of cattle and swine. *Fleischw* 71(7): 813–816, 1991.
53. Schivazappa, C. et al. Lipid oxidation and browning of fresh pork sausages packed under protective atmospheres. *Industria Conserve* 79(4): 441–451, 2004.
54. Pérez-Alvarez, J.A. Aspectos tecnológicos de los productos crudo-curados. In *Ciencia y Tecnología de Carnes*, Y.H. Hui, I. Guerrero and M.R. Rosmini (eds.), pp. 463–492. México: Limusa Noriega Editores, 2006.
55. Bradford, D.D. et al. Low-fat fresh pork sausage patty stability in refrigerated storage with potassium lactate. *J Food Sci* 58(3): 488–491, 1993.
56. Mancini, R.A. et al. How does lactate-enhancement stabilize beef color? In *Proceedings 50th International Congress of Meat Science Technology*, E. Puolanne and M.Ruusunen (eds), pp. 8–13. Helsinki, Finland: University of Helsinki, 2004.
57. Kim, Y.H. et al. Metmyoglobin reduction through lactate-NAD-LDH system *in vivo* and *in vitro*. In *Proceedings 51st International Congress of Meat Science Technology*, pp. 7–12. Baltimore, MD: American Meat Science Association and United States Department of Agriculture, 2005.
58. Seyfert, M. et al. Potassium lactate and fresh pork sausage formulation effects on shelf life in lighted and unlighted display. *J Food Sci* 71: C390–C394, 2006.
59. Kropf, D. and M. Hunt. Effect of display conditions of meat products. In *Procceedings Meat Industry Research Conference*, American Meat Industry, p. 158. Washington: American Meat Institute, 1984.
60. Pagán-Moreno, M.J. et al. The evolution of colour parameters during "chorizo" processing. *Fleischw* 78(9): 987–989, 1998.
61. Aleson-Carbonell, L. et al. Utilization of lemon albedo in dry-cured sausages. *J Food Sci* 68: 1826–1830, 2003.
62. Pérez-Alvarez, J.A. Color. In *Ciencia y Tecnología de Carnes*, Y.H. Hui, I. Guerrero and M.R. Rosmini (eds.), pp. 161–198. México: Limusa Noriega Editores, 2006.
63. Chasco, J., G. Lizaso and M.J. Beriain. Cured colour development during sausage processing. *Meat Sci* 44(3): 203–211, 1996.
64. Rosmini, M.R. Proceso de elaboración de los productos cárnicos fermentados: Caracterización objetiva mediante parámetros de color (PhD Thesis). Valencia, Spain: Universidad Politécnica de Valencia, 1998.
65. Bozkurt, H. and M. Bayram. Colour and textural attributes of sucuk during ripening. *Meat Sci* 73(2): 344–350, 2006.
66. Fernández-López, J. et al. Effect of paprika (*Capsicum annum*) on color of spanish-type sausages during the resting stage. *J Food Sci* 67: 2410–2414, 2002.
67. Khankhalayaeva, I.A. et al. New bacterial preparation for sausage products. *Industriya* 3: 36–37, 2006.
68. Guo, H.L., D.C. Liu, and M.T. Chen. Color stability of chinese-style sausage inoculated with *Staphylococcus carnosus* and *Staphylococcus xylosus*. *Asian Australasian J Animal Sci*. 16(4): 570–574, 2003.
69. Moller, J.K.S. et al. Microbial formation of nitrite-cured pigment, nitrosylmyoglobin, from metmyoglobin in model systems and smoked fermented sausages by *Lactobacillus fermentum* strains and a commercial starter culture. *Eur Food Res Technol* 216(6): 463–469, 2003.
70. Vural, H. The use of commercial starter cultures in the production of Turkish semi-dry fermented sausages. *Food Res Technol* 207(5): 410–412, 1998.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

71. Sayas, M.E. Contribuciones al proceso tecnológico de elaboración del jamón curado: aspectos físicos, fisicoquímicos y ultraestructurales en los procesos de curado tradicional y rápido (PhD Thesis). Valencia, Spain: Universidad Politécnica de Valencia, 1997.
72. Wakamatsu, J., T. Nishimura and A. Hattori. A Zn–porphyrin complex contributes to bright red colour in Parma ham. *Meat Sci* 67(1): 95–100, 2004.
73. Moller, J.K.S. et al. Mass spectrometric evidence for a zinc-porphyrin complex as the red pigment in dry-cured Iberian and Parma ham. *Meat Sci* 75(2): 203–210, 2007.
74. Wakamatsu, J.I. et al. A direct demonstration of the presence of zinc in the acetone-extractable red pigment from Parma ham. *Meat Sci* 76(2): 385–387, 2007.
75. Adamsen, C.E. et al. Changes in Zn–porphyrin and proteinous pigments in italian dry-cured ham during processing and maturation. *Meat Sci* 74(2): 373–379, 2006.
76. Moller, J.K.S. et al. Spectral characterisation of red pigment in Italian-type dry-cured ham. Increasing lipophilicity during processing and maturation. *Eur Food Res Technol* 216(4): 290–296, 2003.
77. Parolari, G., L. Gabba and G. Saccani. Extraction properties and absorption spectra of dry cured hams made with and without nitrate. *Meat Sci* 64(4): 483–490, 2003.
78. Adamsen, C.E. et al. Thermal and photochemical degradation of myoglobin pigments in relation to colour stability of sliced dry-cured Parma ham and sliced dry-cured ham produced with nitrite salt. *Eur Food Res Technol* 218(5): 403–409, 2004.
79. Adamsen, C.E. et al. Studies on the antioxidative activity of red pigments in Italian-type dry-cured ham. *Eur Food Res Technol* 217(3): 201–206, 2003.
80. Morita, H. et al. Red pigment of parma ham and bacterial influence on its formation. *J Food Sci* 61(5): 1021–1023, 1996.
81. Sakata, R. and K.O. Honikel. Investigation of the physical and chemical properties of the red pigment of meat products. *Fleischw* 81(5): 182–190, 2001.
82. Fernández-Ginés, J.M. et al. Colorimetric coordinates evolution during the heat treatment of cooked sausage. *Alimentaria* 335: 87–92, 2002.
83. Pedrielli, R., A. Pizza and M. Franceschini. Production technology of 'Mortadella' sausages: influence of mincing conditions and meat composition on mince characteristics. *Industria Conserve* 73(3): 206–215, 1998.
84. Sakata, R. and Y. Nagata. Mechanism for the colour formation of cooked cured pork by an endogenous factor. *Fleischw* 71(10): 1188–1190, 1991.
85. Bergamaschi, M. et al. Production technology of PGI mortadella bologna sausages: effects of swine diet and storage conditions on the quality of frozen raw material and sausages. *Industria Conserve* 78(3): 251–265, 2003.
86. Sakata, R. and K.O. Honikel. The effect of adding diphosphate on the development and determination of nitrosomyoglobin and the remaining content of nitrite. *Fleischw* 76(9): 951–957, 1996.
87. Ito, T. et al. Electrolytic reduction of heme proteins: attempt to prepare stable natural colorant for sausage. *J Food Sci* 55(6): 1689–1695, 1990.
88. Sakata, R. et al. Augmentation of cooked cured meat colour by nitrosohaemoglobin prepared from cattle blood. *Animal Sci Technol* 64(8): 855–861, 1993.
89. Sakata, R., L. Guisong, and Y. Nagata. Nitrosation of hemoglobin from animal blood as a colorant of meat products. *Animal Sci Technol* 63(12): 1247–1252, 1992.
90. Krysztofiak, K. Possibilities assessment of a colour modification in wiener sausages made with plasma proteins. *Electron. J Polish Agric.-Univ.*, http://www.ejpau.media.pl/series/volume7/issue2/food/index.html. 2004.
91. Kwon, Y.A. Supercritical carbon dioxide extraction of beef and pork for low lipid sausage manufacturing. *Kor J Food Sci Technol* 32(2): 306–311, 2000.
92. Carballo, J., M. Cavestany and F. Jimenez-Colmenero. Effect of light on colour and reaction of nitrite in sliced pork Bologna under different chilled storage temperatures. *Meat Sci* 30(3): 235–244, 1991.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

93. Northcutt, J.K. et al. Kinetics of the light-induced color fading of vacuum-packaged turkey bologna. *J Muscle Foods* 1(3): 169–179, 1990.
94. Ateba, P. and G.S. Mittal. Dynamics of crust formation and kinetics of quality changes during frying of meatballs. *J Food Sci* 59(6): 1275–1278, 1290, 1994.
95. García-Esteban, M. et al. Optimization of instrumental colour analysis in dry-cured ham. *Meat Sci* 63(3): 287–292, 2003.
96. Válková, V. et al. Chemical, instrumental and sensory characteristics of cooked pork ham. *Meat Sci* 77: 608–615, 2007.
97. Onenc, A., M. Serdaroglu and K. Abdraimov. Effect of various additives to marinating baths on some properties of cattle meat. *Eur Food Res Technol* 218(2): 114–117, 2004.
98. Young, L.L., R.J. Buhr and C.E. Lyon. Effect of polyphosphate treatment and electrical stimulation on postchill changes in quality of broiler breast meat. *Poultry Sci* 78(2): 267–271, 1999.
99. Fernández-López, J. et al. Utilización de fibra de origen cítrico en el desarrollo de productos cárnicos funcionales. *Alimentación Equipos y Tecnología* 211: 63–69, 2006.
100. Fernández-Ginés et al. Meat products as functional foods: a review. *J Food Sci* 70: R37–R43, 2005.
101. Pérez-Alvarez, J.A. Alimentos funcionales. In *Alimentos Funcionales y Dieta Mediterránea*. J.A. Pérez-Alvarez, J. Fernández-López and E. Sayas (eds.), pp. 1–12. Elche, Spain: Universidad Miguel Hernández, 2003.
102. Pszczola, D.E. Making fortification functional. *Food Technol* 59(4): 44, 2005.
103. Aleson-Carbonell, L. et al. Utilization of lemon albedo in dry-cured sausages. *J Food Sci* 68: 1826–1830, 2003.
104. Aleson-Carbonell, L. et al. Quality characteristics of a non-fermented dry-cured sausage formulated with lemon albedo. *J Sci Food Agric* 84: 2077–2084, 2004.
105. Fernández-López, J. et al. Effect of paprika (*Capsicum annum*) on colour of Spanish-type sausages during the resting stage. *J Food Sci* 67: 2410–2414, 2002.
106. Sayas-Barbera, E., J. Fernández-López and J.A. Pérez-Álvarez. Elaboración de embutidos crudo-curados. In *Industrialización de Productos de Origen Animal*. J.A. Pérez-Alvarez, J. Fernández-López and E. Sayas (eds.), pp. 55–79. Elche, Spain: Universidad Miguel Hernández, 2003.
107. Vuorela, S. et al. Effect of plant phenolics on protein and lipid oxidation in cooked pork meat patties. *J Agric Food Chem* 53: 8492–8497, 2005.
108. Segura-Ferrero, M. Contribución al estudio de pastas finas de hígado Sci (BS Thesis). Orihuela, Spain: Miguel Hernandez University, 2007.
109. Byrne, M. Low fat with taste. *Food Eng Int* 22(6): 36–41, 1997.
110. Lee, E.J. and Ahn, D.U. Quality characteristics of irradiated turkey breast rolls formulated with plum extract. *Meat Sci* 71(2): 300–305, 2005.
111. Sánchez-Escalante, A. et al. Utilization of applesauce in a low-fat bologna-type product. *Food Sci Technol Int* 65(5): 379–386, 2000.
112. Fernández Ginés, J.M. et al. Lemon albedo as a new source of dietary fiber: application to bologna sausages. *Meat Sci* 67: 7–13, 2004.
113. Fernández-López, J. et al. Application of functional citrus by-products to meat products. *Trends Food Sci Technol* 15: 176–185, 2004.
114. Fernández-Ginés, J.M. et al. Effect of storage conditions on quality characteristics of bologna sausages made with citrus fiber. *J Food Sci* 68: 710–715, 2003.
115. Garcia, M.L., E. Caceres and M.D. Selgas. Utilisation of fruit fibres in conventional and reduced fat cooked-meat sausages. *J Sci Food Agric* 87(4): 624–631, 2007.
116. Pietrasik, Z. and Z. Duda. Effect of fat content and soy protein/carrageenan mix on the quality characteristics of comminuted, scalded sausages. *Meat Sci* 56: 181–188, 2000.
117. Pacheco-Delahaye, E. and N. Vivas-Lovera. Effect of defatted corn germ flour and rice bran on some chemical, physical and sensory properties of sausages. *Acta Cient Venez* 54(4): 274–283, 2003.
118. Yilmaz, I. Effects of rye bran addition on fatty acid composition and quality characteristics of low-fat meatballs. *Meat Sci* 67: 245–249, 2004.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

119. Muguerza, E. et al. Effect of fat level and partial replacement of pork backfat with olive oil on the lipid oxidation and volatile compounds of Greek dry fermented sausages. *J Food Sci* 68: 1531–1536, 2003.
120. Vural, H. and I. Javidipour. Replacement of beef fat in frankfurters by interesterified pal, cottonseed and olive oil. *Eur Food Res Tech* 214: 465–468, 2002.
121. Hur, S.J. et al. Effects of conjugated linoleic acid on color and lipid oxidation of beef patties during cold storage. *Meat Sci* 66: 771–775, 2004.
122. Østerlie, M. and J. Lerfall. Lycopene from tomato products added minced meat: effect on storage quality and colour. *Food Res Int* 38: 925–929, 2005.
123. Ruíz-Cano, D. et al. Orange fiber extracts: concentration effect and processing time upon reflectance spectrum of dry-cured sausages. In *International Symposium on Meat Safety: from Abattoir to Consumer* P. Fito and F. Toldrá (eds.), Valencia, 2007.
124. Gimeno, O., I. Astiasaran and J. Bello. A mixture of potassium, magnesium, and calcium chlorides as a partial replacement of sodium chloride in dry fermented sausages. *J Agric Food Chem* 46(10): 4372–4375, 1998.
125. Ibanez, C. et al. Dry fermented sausages elaborated with *Lactobacillus plantarum* and *Staphylococcus carnosus*. I. Effect of partial replacement of NaCl with KCl on the stability and the nitrosation process. *Meat Sci* 44(4): 227–234, 1996.
126. Cofrades, S. et al. Restructured beef with different proportions of walnut as affected by meat particle size. *Eur Food Res Technol* 218(3): 230–236, 2004.
127. Koo, S.G. et al. Quality properties of fish meat paste containing enoki mushroom (*Flammulina velutipes*). *J Kor Soc Food Sci Nutr* 30(2): 288–291, 2001.
128. Tan, S.S. et al. Chemical, physical and sensory properties of chicken frankfurters substituted with palm fats. *Int J Food Sci Nutr* 52(1): 91–98, 2001.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 8

Texture Analysis

Shai Barbut

Contents

8.1 Background 121
8.2 Shear Test 122
8.3 Penetration 124
8.4 Single Compression and Texture Profile Analyses 125
8.5 Tension 127
8.6 Torsion 127
8.7 Small Deformation 128
8.8 Other Noncontact Methods 128
References 129

8.1 Background

Studying and evaluating the textural parameters of meat products is an essential part of being able to offer consumers high quality and consistent products. A whole muscle product, such as a beefsteak, is unacceptable if it is too tough to chew due to high levels of connective tissue. On the other hand, if the meat does not have enough connective tissue (e.g., turkey breast from heavy toms), it would be too mushy and could fall apart. Such textural parameters can be the result of numerous factors (e.g., breed and age of the animal, stress prior to slaughter, chilling, and cooking methods). Therefore, studying and understanding factors contributing to the texture of meat products is of great interest to breeders, farmers, the meat industry, and obviously the consumer. Overall, meat textural parameters can be measured by different tests, which usually are classified as large and small deformation tests. The large deformation tests, which are more common, usually include shear, penetration, compression, tension, and torsion (Figure 8.1).

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

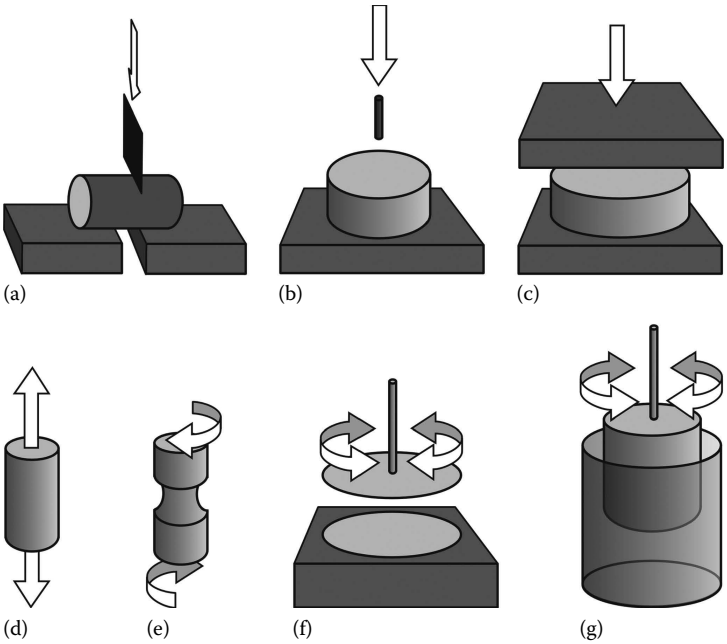


Figure 8.1 Different texture analysis tests: (a) shear; (b) penetration; (c) compression, which can be single or double for the texture-profile-analysis test; (d) tension; (e) torsion; (f) small oscillatory deformation between parallel plates; (g) similar to "f" but a bob and cup configuration. See text for further explanation. (Illustrated by O. Barbut, School of Engineering, University of Toronto, Canada.)

The small deformation tests (i.e., nondestructive testing) are used more for research purposes and mainly include dynamic scanning rigidity monitoring, using a low-strain or a low-stress rheometer. The small deformation tests are mostly used for monitoring gelation processes (e.g., heating of meat proteins and cooling of gelatin) and interactions among different meat and nonmeat gelling components.

8.2 Shear Test

The shear test was one of the first developed to determine the toughness of raw/cooked whole muscle and/or meat products [1]. The most popular test is the Warner Bratzler Shear (WBS), named after its inventor [2]. Bratzler explained that, "It is of paramount importance that some method of measuring variation in tenderness be devised in order that the factors that cause this variation may be studied." Overall, the procedure employs a single blade used to cut a core meat sample (Figure 8.1a). The result provides a measure of the force required to shear the sample (Figure 8.2a). Instrumental determination of texture, or tenderness, is usually evaluated on intact pieces or core samples, large enough to ensure representative sampling so that the treatment effect can be accurately measured. Various researchers have noted that factors such as sample size, location within the muscle, and orientation of the fiber relative to the shearing blade are critical to ensure reproducible results. Evaluating the same sample but positioning the muscle fiber perpendicular or parallel to the blade will result in different outcomes since it takes more force to shear the fibers positioned

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

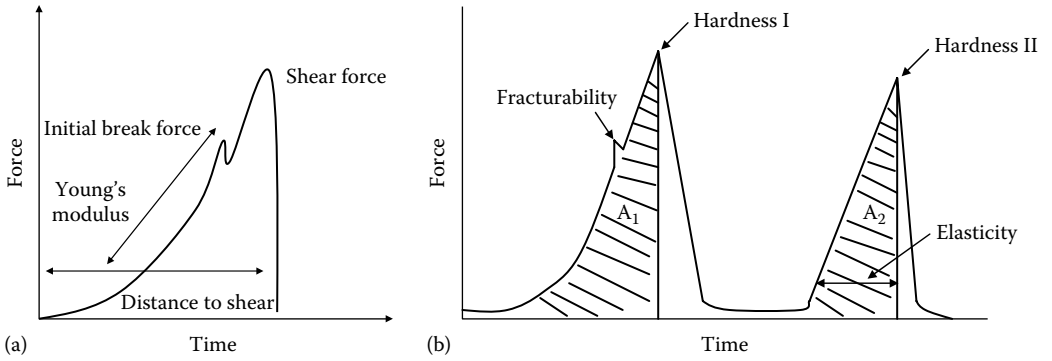


Figure 8.2 Generalized force deformation curve for a single compression test (a) and for a two cycle compression test also known as texture profile analysis (b). For texture profile analysis: cohesiveness = A2/A1; gumminess = hardness I × cohesiveness; chewiness = gumminess × elasticity. (Based on Bourne, M. C., *Food Technol.*, 32(7), 62, 1978.)

perpendicular to the blade; the standard WBS test calls for perpendicular positioning. Using a modified WBS shear apparatus (texture analyzer fitted with a flat Volodkewick shear blade), Hansen et al. [3] reported a significant transverse muscle variation in pork *longissimus dorsi* muscle, that is, increased shear force from dorsal to lateral sampling position. Sensory evaluation revealed a similar nonsignificant trend from dorsal to medial sampling position. Both WBS and sensory analysis showed that muscles from left and right sides of the carcass differed significantly. This was postulated to be caused by a greater amount of work performed by right muscles compared to left muscles. As the authors indicated, "in general, sensory and instrumental analyses were found largely to be predictive indexes of each other." They also stressed that the significant variation between longitudinal locations should be taken into account when designing an experiment.

Another device used to evaluate food texture is the Allo-Kramer Shear (AKS), introduced in the 1950s. It has been adapted to meat texture and is routinely used by researchers and quality control personnel. The same considerations of size, location, and fiber orientation have been noted for the AKS as for the WBS. The AKS employs a cell consisting of 10–13 blades guided into a square box to shear the sample. Lyon and Lyon [4] compared the effect of broiler breast meat deboning time by using both the WBS and AKS methods; they correlated the results with a sensory panel. For the WBS, intact 1.9-cm-wide strips of cooked meat were evaluated. For the AKS, 20-g strip portions of 1 cm^2 (top size) were evaluated. Sensory characteristics were evaluated by category scales—untrained panel (results reported in Table 8.1) and descriptive analysis—trained panel (results not presented here).

The shear values of the intact (WBS) and diced (AKS) samples indicated significant differences due to deboning times (Table 8.1). Both shearing procedures were sensitive enough to discriminate differences among each of the three deboning times. As indicated by the authors, reduction in shear values as postmortem deboning time increases is well documented in the literature. The sensory panel reported the same trend, and results for tenderness were highly correlated with both instrumental methods (Table 8.1). Juiciness was not found to be affected by deboning time. The overall texture acceptability was significantly affected by deboning time and also showed high correlations with both instrumental methods.

A typical force deformation curve for the shear test is shown in Figure 8.2a. Besides the peak shear force, other parameters such as work required to shear (area under the curve), initial fracture

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 8.1 Warner-Bratzler and Allo-Kramer Shear Values of Intact and Diced Cooked (80°C) Samples of Broiler Breasts Deboned at Three Postmortem (PM) Times as Well as Sensory Evaluations (Category Scale—Untrained Panel) of Cooked Diced Chicken

	Texture		*Sensory*		
	Warner-Bratzler[a] *(intact) (kg)*	*Allo-Kramer*[b] *(20-g diced; kg/g)*	*Juiciness*[c]	*Tenderness*[c]	*Acceptability*[d]
Deboning time (h PM)					
2	9.5 ± 3.9[e]	5.2 ± 1.0[e]	3.5 ± 1.3	2.5 ± 1.3[g]	2.0 ± 0.9[g]
6	4.7 ± 1.6[f]	3.4 ± 0.8[f]	3.4 ± 1.2	3.8 ± 1.2[f]	2.6 ± 0.9[f]
24	3.2 ± 0.9[g]	2.2 ± 0.2[g]	3.5 ± 1.3	5.1 ± 0.8[e]	3.0 ± 0.9[e]
Correlations (R values)					
With Warner-Bratzler			0.06	−0.90	−0.92
With Allo-Kramer			0.00	−0.99	−0.93

[a] Bench-top Warner-Bratzler device was used to shear a 1.9-cm-wide intact strip.
[b] Multiple bladed Allo-Kramer attached to an Instron was used to shear 20 g of diced sample.
[c] Category scales: 1 = very dry, tough to 6 = very juicy, tender.
[d] Category scales: 1 = poor to 5 = excellent.
[e–g] Values ($x \pm$ SE) within a column with no common superscript differ significantly ($p \leq 0.05$). For texture, mean values are averages of 66 observations (22 birds × 3 replications) for each deboning time. For sensory, 22 panelists × 3 replications.

Source: Adapted from Lyon, B. G., Lyon C. E., *Poultry Sci.*, 75, 812, 1996.

force, and the Young's modulus (slope of the curve) can be obtained. It should be pointed out that although the WBS is the most frequently cited texture analysis test used by meat researchers, variations in test procedure (sample preparation, dimensions, end point cooking temperature, cross head speed, blade dimension) are fairly common among research groups [1]. Some call their procedure a modified WBS, while others give it a more specific name such as the slice-shear force [5]; the latter has been used fairly extensively by the group cited as well as by others. Overall, it appears that developing a universal procedure can benefit us all and make it easier (or at least possible) to compare results among different research groups. However, as concluded by Janz and Aalhus [1], "at the moment there is no reason to discount the use of specialized procedure, provided methodology is reported in full" (i.e., they also recommended moving toward a standardized test).

8.3 Penetration

In this test, a probe descends into the product at a constant speed (Figure 8.1b), with the force required to rupture the sample being recorded. A variety of different probes have been used, including flat and rounded tips with different diameters. The test can be used to determine the

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

resistance to puncture in products such as cooked whole muscle, ground and comminuted meat products, or fine gels (e.g., Jello). The results are commonly used to compare relative toughness/hardness (see also the puff test discussed in Section 8.8). This is an easy test to perform, and some companies use it on a routine basis as a rapid quality control test. The gelatin industry, for example, employs the test to standardize gelatin strength, also known as "bloom." Another area where this test can be useful is in monitoring changes in a raw meat batter during cooking. The test is applicable for this purpose because the researcher starts with a paste-like, raw meat batter (which cannot be subjected to a shear test); later, this stiffens during the cooking process. An example of results obtained for a poultry meat batter prepared with 2.5% salt, showed penetration force (using a 9 mm diameter flat tip probe attached to a texture analyzer) rising from 30 to 43, 60, 190, 355, and 475 N as temperature was increased from 20 to 40, 50, 55, 60, and 70°C, respectively [6]. The transition from a viscous to a more rigid sample was clearly seen at the point where myofibrillar protein started to gel, at about 50–55°C. The amount of extractable protein was also used to evaluate the quantity of soluble proteins going into structure building (i.e., gelling). As temperature was raised, the amount decreased from 1.6 to 1.5, 1.4, 1.2, 1.0, and 0.4 mg/mL at 20, 40, 50, 55, 60, and 70°C, respectively. The changes could also be followed under a microscope as the protein strands became thicker and the number of connections among them increased as temperature was raised.

8.4 Single Compression and Texture Profile Analyses

In this configuration, a sample is compressed axially between two flat plates (Figure 8.1c). The test can be performed as a single compression or double compression. The single-compression test can be done to failure, meaning that the sample is compressed until it totally breaks. Alternately, the test can be done to a predetermined point where the deformation is measured. Two extreme food examples would be a hard candy and a marshmallow. In the first case, when force is slowly applied, the sample will hardly deform; however, at a certain point, it will shatter. In the second case, a relatively low force will quickly deform the sample, but the sample can easily recover (highly elastic sample). Meat samples fall in between these two extremes and show moderate elasticity. Voise et al. [7] reported that in a single compression test, the force required to produce failure in a wiener-type product they studied was strongly correlated ($R = 0.89$) with sensory chewiness.

A two-cycle compression test, known in the food industry as texture profile analysis (TPA), was developed by a group of scientists at General Foods in the early 1960s. A cylindrical sample is compressed to a certain predetermined deformation during the first cycle, pressure is released, and then the sample compressed a second time [8]. The General Foods group has established some very useful parameters that correlate well with sensory data (Figure 8.2b). The test is commonly used by food scientists for various products. However, over the years, different test parameters have been used by various researchers, which has made it difficult, if not impossible in some cases, to compare results from different laboratories. Mittal et al. [9] reviewed test parameters reported in the literature to evaluate meat samples, and indicated that meat specimen length or height (L) varied from 10 to 20 mm, diameter (D) from 13 to 73 mm, and D/L ratio from 1 to 4. The compression ratio varied from 50 to 85%, and compression speed from 5 to 200 mm/min. The effects of varying D/L, speed, and compression rate are shown in Table 8.2. The results are for a commercial-type frankfurter made of beef meat (55.9% water, 28.5% fat, 12.6% protein, and 2.9% ash). The authors have also tested a whole muscle product (corned beef)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 8.2 Duncan's Test Results for Different Texture Profile Analysis Parameters of Frankfurters

	H1 (N/cm²)	*H2 (N/cm²)*	*E (m/cm²)*	*COH*	*GUM (N/cm²)*	*CHEW (J/cm⁴)*
Mean Values						
D/L	30.11[a]	23.47[a]	0.024[c]	0.405[a]	11.76[a]	0.33[c]
2.0	27.39[b]	20.40[b]	0.047[b]	0.388[a]	10.25[b]	0.56[b]
1.5	24.14[c]	14.52[c]	0.084[a]	0.338[b]	7.69[c]	0.77[a]
1.0						
Speed (cm/min)						
2.0	29.51[a]	20.64[a]	0.053[a]	0.369[a]	10.41[a]	0.58[a]
1.0	26.81[b]	20.16[a]	0.052[a]	0.369[a]	10.27[a]	0.57[a]
0.5	25.32[c]	17.59[b]	0.051[a]	0.366[a]	9.02[b]	0.50[a]
Compression (%)						
25	22.72[c]	20.52[a]	0.070[a]	0.686[a]	15.58[a]	1.05[a]
50	34.41[a]	18.51[b]	0.055[b]	0.299[b]	10.54[b]	0.50[b]
75	24.50[b]	19.36[ab]	0.031[c]	0.147[c]	3.59[c]	0.11[c]
Correlation Coefficients						
D/L	0.38[d]	0.63[d]	–0.78[d]	0.11	0.29[d]	–0.37[d]
Speed	0.27	0.19	0.02	–0.01	0.09	0.06
Compression	0.11	–0.08	–0.52[d]	–0.92[d]	–0.85[d]	–0.78[d]

[a–c] Data with the same superscript letter in a column, within a category, are not significantly different at $p > 0.05$ level.

[d] $p \leq 0.0001$.

Note: H1 = harness-1; H2 = hardness-2; E = springiness; COH = cohesiveness; GUM = gumminess; CHEW = chewiness; *D/L* = diameter to length ration.

Source: Adapted from Mittal, G. S., Nadulski, R., Barbut, S., Negi, S. C., *Food Res. Intern.*, 25, 411, 1992.

and a ground meat (salami) product; results are not included here. The data show that a decrease in *D/L* resulted in a lower hardness I and II, cohesiveness, and gumminess, while springiness and chewiness increased. Increasing the compression ratio resulted in decreased springiness, cohesiveness, gumminess, and chewiness. According to Peleg [10], at the same deformation rate, a shorter specimen is actually deformed at a higher strain rate, and therefore should exhibit higher stress than those of a longer specimen and the same strain. Thus, TPA parameters are comparable when the tests are performed by a standard procedure. From the results reported in Table 8.2 and results obtained for the salami and corned beef, Mittal et al. [9] recommended the use of the following test parameters: *D/L* = 1.5, compression ratio = 75%, and rate of compression

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

of 1–2 cm/min. As with the WBS test previously discussed, employing such standard conditions should be beneficial in allowing for a meaningful comparison of results among different laboratories.

Several researchers have compared the use of TPA to other methods such as the WBS test. Caine et al. [11], for example, have indicated that TPA explained more of the variation in subjective sensory tenderness of beef rib steaks they evaluated compared to the WBS test. However, this is not necessarily a universal finding.

8.5 Tension

The test is done by pulling apart a meat sample (Figure 8.1d), and is done to determine the strength of products such as sliced cooked meats. If a whole muscle product is tested, the orientation of the muscle fibers is, again, very important because muscle fibers pulled at 90° to their longitudinal axis will require lower force than fibers pulled along their longitudinal axis.

Results obtained for commercial whole muscle turkey breast meat products showing good slice integrity, with an average value of 2.5 N, while those from a product that showed poor sliceability had an average value of 1.1 N (sample size: 150 mm [long] × 20 [wide] × 3 [thick], pulled apart at 50 mm/min). The samples were evaluated after a meat processor got a product complaint indicating a problem obtaining thin slicing (also called shaving). Under the microscope, the poor integrity areas revealed poor connective tissue binding among the individual muscle fibers.

8.6 Torsion

The torsion test is usually preformed by twisting a sample that has been carved into a dumbbell shape (Figure 8.1e). The controlled rotation can be done with a viscometer after the sample ends have been glued to plastic disks. The force required to break the sample is measured and is used to calculate true shear strain and shear stress values. The advantage of using this test is that volume changes are minimized and the squeezing out of water prior to the breakpoint (which typically occurs in a compression test) is avoided. The test has been shown to reveal differences in muscle protein gelation and functionality (Table 8.3). The table indicates that shear strain is a measure of protein functionality (i.e., the ability of the salt-soluble proteins to form a heat-induced

Table 8.3 Degree of Influence of Different Factors on Failure Stress and Strain of Processed Muscle Foods

Factor	*Shear Stress*	*Shear Strain*
Protein functionality	Strong	Strong
Protein concentration	Strong	Weak
Filler ingredients	Strong	Weak
Thermal process	Strong–moderate	Weak

Source: Data from Hamann, D.D., *Food Technol.*, 42(6), 66, 1988.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

cohesive gel). Shear stress is also dependent on protein functionality, but it is strongly influenced by other factors as well. Overall, shear stress relates to sensory hardness and shear strain to sensory cohesiveness. Hamann [12] described the relationships between shear strain and shear stress in terms familiar to a customer evaluating a food sample: A product with low shear strain and shear stress = mushy; high shear strain and low shear stress = rubbery; high shear stress and low shear strain = brittle; high shear strain and stress = tough. An important implication of the data presented in Table 8.3 is that it is more difficult to modify sensory cohesiveness by adding different ingredients than it is to modify sensory hardness of meat gels. Montejano et al. [13] compared torsion and TPA results with sensory notes (springiness, hardness, cohesiveness, denseness, chewiness, gel persistence). Overall, these two instrumental parameters correlated strongly ($R = 0.83$), as did the six sensory notes. Stress and TPA hardness correlated strongly ($R = 0.94$) but did not correlate as strongly with the sensory notes as did the parameters based on deformation to failure.

8.7 Small Deformation

This test is used to monitor a process such as meat protein progressive gelation during heating; it involves a scanning rigidity evaluation, applying low strain or stress to a sample (Figures 8.1f and g). Several studies have shown that the information is valuable in monitoring physical changes in meat proteins and possible interactions with other nonmeat ingredients (e.g., soy proteins and hydrocolloide gums) during the gelation process. These interactions can be related to molecular changes [12]. It should be pointed out that several studies have indicated that results are well correlated with sensory texture and the penetration test, while others have indicated that results are not necessarily related to the shear test and TPA. The reason for the latter is that changes in rigidity provide circumstantial evidence of changes taking place during gelation (structure-building phase). These changes are associated with protein unfolding, bonding of molecules, and interactions with other nonmeat components such as soy proteins and gums.

One of the first laboratory devices employed a microscope coverslip glass submerged in a meat protein solution. The coverslip was moved up and down, at a very slow rate and over a short distance, while the sample was heated. The resistance to movement was recorded and plotted against temperature to study the effect of actin to myosin ratio on the gel formed during heating [12]. The data provided valuable information on gelation temperatures, effects of the myosin:actin ratio, and the magnitude of protein–protein interactions during the actual gel forming stages. Today, various commercial computer-controlled stress/strain rheometers are available in the market that provide very precise motion and temperature control, as well as easy calculations. An example of results obtained with a commercial controlled stress rheometer is shown in Figure 8.3. Kerry et al. [14] used a rheometer in the oscillatory mode to show that adding modified starch or pectin significantly increased storage modules (G′) compared to a control. The results demonstrate a synergistic effect during the gelation of the meat protein system at ≥55°C. Sodium alginate, on the other hand, caused a disruption in the meat protein matrix formation. Upon cooling, further texture building by the starch and pectin was observed as the two polysaccharides formed more hydrogen bonds.

8.8 Other Noncontact Methods

Over the past few years there has been a drive to develop rapid methods for fast online evaluations. The area of greatest interest is tenderness; several methods, mainly based on light reflectance and

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

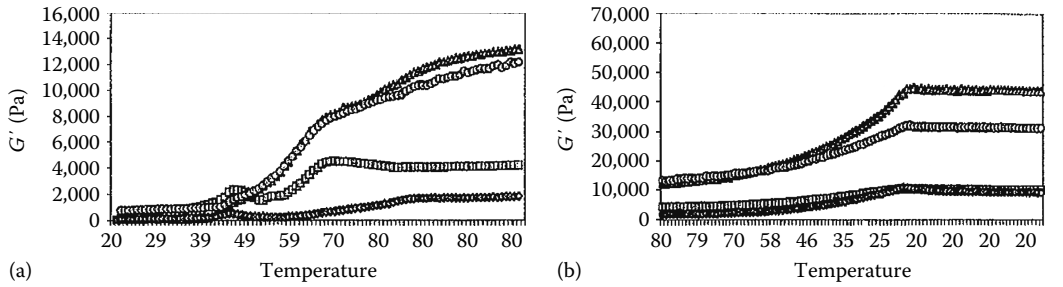


Figure 8.3 Plots of storage modules G′ (Pa) values as a function of increasing (a) and then decreasing (b) temperature (1°C per min) of meat exudates prepared with whey protein (control), and treatments with 2% modified potato starch (Δ), 2% low-methoxy pectin (o), and 0.5% sodium alginate (◊). (From Kerry, J., Morrissey, P., Buckley, D., *J. Sci. Food Agri.*, 79, 1260–1266, 1999. With permission.)

response to applied pressure, have been or are under development for commercial use. For an overall reference explaining the basic principles of most such methods, the reader is referred to Swatland [15]. The goal of such methods is to directly or indirectly predict the texture of meat and other food products. Two examples are an optical sensor and an applied stress method. Shackelford et al. [16] reported an online application of visible and near infrared spectroscopy to U.S. Select beef carcasses during grading, using shear force and trained sensory panel tenderness ratings as their basic reference methods. They indicated that "the technology might be useful for identifying U.S. Select carcasses that excel in *longissimus* tenderness." Using an applied stress in the so-called puff test is based on a controlled puff of air (applied from a nozzle) that impinges on a surface. The deformation at the center of this small indention is measured with a laser displacement sensor [17]. Fresh meat and meat products are some of the items being tested, but currently there is no commercial puff equipment available on the market. This will probably change as the demand for fast, online individual carcass grading/evaluation is growing.

References

1. Janz, J. A. M., Aalhus, J. L. 2002. The complexity of measuring beef tenderness using Warner Bratzler shear methodology for whole muscle samples. In *Food Science and Product Technology.* Eds. Nakano, T., and Ozimek, L. Signpost Publication, Kerala, India.
2. Bratzler, L. J. 1932. MSc. Thesis. Meat Texture Analysis. Kansas State College of Agriculture and Applied Science.
3. Hansen, S., Aaslyng, M., Byrne, D. 2004. Sensory and instrumental analysis of longitudinal and transverse textural variation in pork longissimus dorsi. *Meat Sci*. 68:611.
4. Lyon, B. G., Lyon, C. E. 1996. Textural evaluations of cooked diced broiler breast samples and mechanical methods. *Poultry Sci.* 75:812.
5. Shackelford, S. D., Wheeler, T. L., Koohmaraie, M. 2004. Technical note: use of belt grill cookery and slice shear force for assessment of pork longissimus tenderness. *J. Animal Sci.* 82:238.
6. Barbut, S., Gordon, A., Smith, A. 1996. Effect of cooking temperature on the microstructure of meat batters prepared with salt and phosphate. *Lebensm.-Wiss. u.-Technol*. 29:475.
7. Voisey, P. W., Randall, C. J., Larmond, E. 1975. Selection of an objective test of wiener texture by sensory analysis. *Can. Inst. Food Sci. Technol. J.* 8(1):24.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

8. Bourne, M. C. 1978. Texture profile analysis. *Food Technol*. 32(7):62.
9. Mittal, G. S., Nadulski, R., Barbut, S., Negi, S. C. 1992. Textural profile analysis text conditions for meat products. *Food Res. Intern*. 25:411.
10. Peleg, M. 1977. The role of the specimen dimensions in uniaxial compression of food materials. *J. Food. Sci*. 41:649.
11. Caine, W. R., Aalhus, J. L., Best, D. R., Dugan, M. E. R., Jeremiah, L. E. 2003. Relationship of textural profile analysis and Warner-Bratzer shear force with sensory characteristics of beef rib steaks. *Meat Sci*. 64:333–339.
12. Hamann, D. D. 1988. Rheology as a means of evaluating muscle functionality of processed foods. *Food Technol*. 42(6):66.
13. Montejano, J. G., Hamann, D. D., Lanier, T. C. 1985. Comparison of two instrumental methods with sensory texture of protein gels. *J. Texture Studies* 16:403.
14. Kerry, J., Morrissey, P., Buckley, D. 1999. The rheological properties of exudates from cured porcine muscle: effects of added polysaccharides and whey protein/polysaccharide blends. *J. Sci. Food Agri*. 79:1260–1266.
15. Swatland, H. J. 1995. *On-Line Evaluations of Meat*. Technomic Publishing. Lancaster, PA.
16. Shackelford, S. D., Wheeler, T. L., Koohmaraie, M. 2005. On-line classification of US Select beef carcasses for longissimus tenderness using visible and near-infrared reflectance spectroscopy. *Meat Sci*. 69:409–415.
17. Bramelis, F. R., Baerdemaeker, J. G. 2006. Use of the food texture puff device to monitor milk coagulation. *J. Dairy Sci*. 89:29.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 9

Flavor of Meat Products

Mónica Flores

Contents

9.1 Introduction 131
9.1.1 Flavor Precursors 132
9.1.2 Flavor Analysis 132
9.2 Flavor of Cured Meat Products 134
9.2.1 Bacon 134
9.2.2 Frankfurter 137
9.2.3 Cooked Ham 137
9.2.4 Roast Beef 137
9.3 Flavor of Dry-Cured Meat Products 138
9.3.1 Dry-Cured Ham 138
9.3.2 Dry-Fermented Sausages 138
References 142

9.1 Introduction

Meat products constitute a wide variety of products in terms of sensory characteristics. Their diversity of colors, flavors, and textures is due to different traditional practices. There are many different meat products, but in general, meat products are cured by the addition of sodium nitrite and salt along with other additives, such as sugars, certain reducing agents, and appropriate seasonings that impart specific properties to the final product. These cured meat products can be grouped in two major groups—dry and wet curing [1]. During dry curing, the meat is mixed or rubbed on the surface with a dry cure containing salt plus nitrate or nitrite and without any added water, followed by a drying stage. The most representative products of the dry curing process are dry-cured

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

ham and dry-fermented sausages. In the wet curing process, a pickle injection or brine solution is used as the vehicle for cure penetration into the meat, and afterwards the meat is cooked to obtain the final sensory characteristics [1].

Some of the most well-known dry-cured meat products are those manufactured using pork meat such as dry-cured hams—Parma and San Daniele hams (Italy), Serrano and Iberian hams (Spain), Bayonne ham (France), and Jinhua ham (China). Other dry-cured meat products are processed from beef meat, as in the case of jerked beef (Brazil) and pastirma (Turkey). However, many different dry-fermented products are manufactured around the world; some of them are known as salami (Italy), saussicon (France), salchichon, and chorizo (Spain). The most representative products obtained from wet curing processes are bacon, roast beef, frankfurters, and cooked ham.

Flavor is one of the most important factors contributing to the quality of meat products. Raw meat possesses little odor and only a mild serum-like taste that has been described as salty, metallic, and bloody with a sweet aroma [2]. The flavor of meat products depends on composition and processing conditions; it can also be modified by the use of spices and condiments. Moreover, thousands of volatile compounds have been identified in meat products, but the exact contribution of each compound to flavor is not yet known.

9.1.1 Flavor Precursors

The constituents of raw pork meat act as important taste compounds, flavor enhancers, and aroma precursors. These constituents are essentially proteins, amino acids, nucleotides, sugars, lipids, vitamins, and other compounds. During meat processing, these constituents undergo degradation reactions, forming hundreds of volatile compounds with the characteristic pork flavor [2]. Generally, pork flavor has not been attributed to a single chemical compound, although it is frequently accepted that meaty notes are produced by sulfur-containing compounds generated from water-soluble precursors in lean meat. However, fat and fat-soluble substances contribute to flavor differences among species [3].

The main reactions involved in the development of flavor in meat products are lipid degradation, thiamine degradation, Strecker degradation, degradation of ribonucleotides, microbial amino acid degradation, carbohydrate degradation (heating or fermentation), and Maillard reactions [4].

9.1.2 Flavor Analysis

In the study of the flavor of meat products it is necessary to obtain a sufficient amount of volatile compounds. The sample used should be a good representative of the product with a good aroma and without off-flavors or artifacts.

Sample preparation will depend on the technique used for volatile extraction due to the number of factors that affect it. This is the case for the concentration levels of aroma compounds that generally are low and for the matrix effect, because the complex matrices contain lipids, proteins, and carbohydrates that complicate the isolation process. Other factors affecting the extraction are the complexity of food aroma composed of a large number of different chemical compounds with different volatility and, finally, the instability of aroma components [5].

The analysis of volatile compounds is generally accomplished by an extraction step, followed by concentration, chromatographic separation, and subsequent detection. Thermally labile compounds may decompose in the heated zones of the instruments, producing a chromatographic profile that it is not truly representative of the sample.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

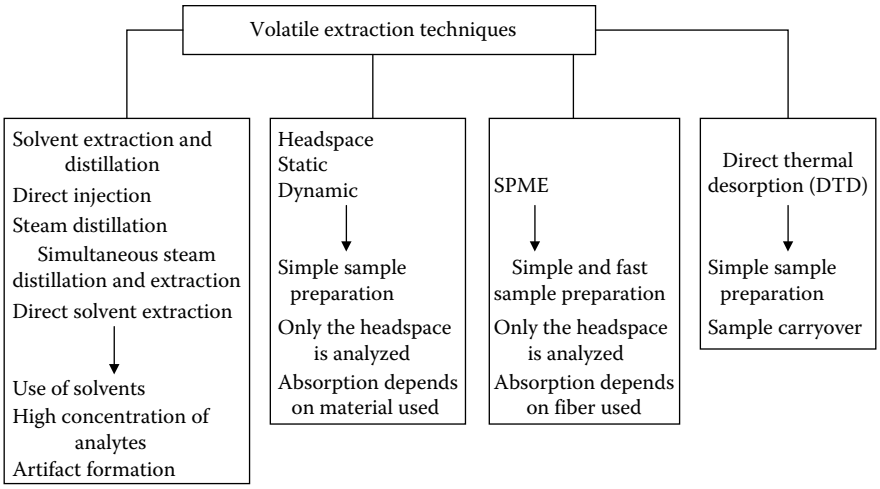


Figure 9.1 Extraction techniques of volatile compounds.

The techniques used for analyzing food aroma have been widely described by Marsili [6] and Cadwallader and MacLeod [7]. Figure 9.1 summarizes the extraction methods, including the main advantages and disadvantages. Generally, the most common techniques are solvent extraction and headspace analysis. Distillation and solvent extraction techniques are critical to assess the organoleptic quality of the isolate. This evaluation is made to ensure that decomposition and loss of desirable components have not occurred.

The headspace techniques do not use solvents to remove the analytes from the sample matrix, avoiding the presence of the solvent peak in the chromatographic elution. This fact could be of special interest when the important analytes are of low boiling points [8].

Currently, solid-phase micro extraction (SPME) is becoming a suitable technique to analyze food aroma. In this method, the analytes are adsorbed onto a coating and an exhaustive extraction is not necessary; ultimately, an equilibrium is reached between the matrix and the stationary phase coating the fiber [9].

Direct thermal desorption consists of sparging the volatiles from the sample matrix and transferring them directly onto the head of the chromatographic column. This technique allows the qualitative analysis of volatile compounds without sample preparation [10].

In past years, flavor research seems to have been directed not only to the identification of compounds but also to characterizing their components based on their organoleptic importance; one of the major problems in aroma research is to select those compounds that significantly contribute to aroma. Different techniques have been used to distinguish the most potent odorants. In the beginning, the techniques used required the identification and quantification of a great number of volatile compounds and the determination of their threshold values, calculating what was known as "aroma value" [11]. To select the aroma-active components from a complex mixture, several techniques using gas chromatography with olfactometry (GCO) detection have been described (Figure 9.2).

In GCO analyses, the effluent of a GC column is analyzed by human subjects describing the eluted compounds. However, the description process is not an easy task, because several compounds exhibit different odor qualities at different concentrations. In addition, panelists analyzing the effluent can use different terms to describe the same odor and can suffer fatigue, sensory saturation, and adaptation.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

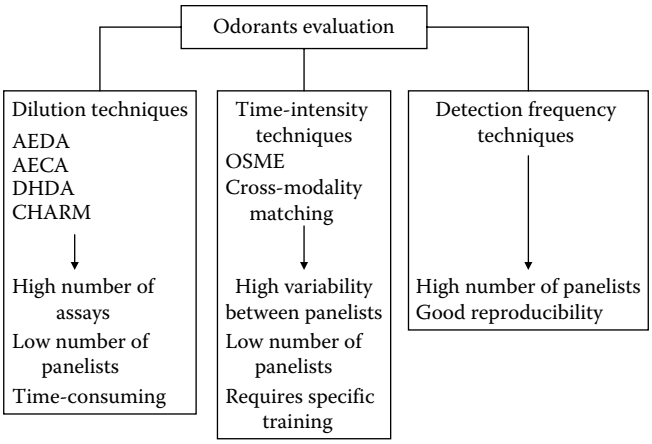


Figure 9.2 Techniques to evaluate odorants. AEDA, aroma extract dilution analysis; AECA, aroma extract concentration analysis; DHDA, dynamic headspace dilution analysis; CHARM, combined hedonic aroma response; *osme*, Greek word meaning smell.

The different olfactometry techniques developed (Figure 9.2) are dilution, time intensity, and frequency techniques. In dilution techniques, the key odorants are ranked in order of potency by sniffing a food extract and its successive dilutions. The dilution factor (DF) value is the last dilution at which an odor compound is detected; this technique is known as aroma extract dilution analysis (AEDA) [12,13]. Several modifications of this technique have been proposed [14–17].

In time-intensity techniques, the panelist directly records the intensity of the compound perceived, using a computerized scale. The main problem with this technique is that it requires a well-trained panelist [18,19]. On the other hand, the detection frequency method uses a number of panelists detecting an odor in the effluent as a measure of the intensity of a compound [20,21].

9.2 Flavor of Cured Meat Products

The study of the flavor of meat products has been done by the identification of volatile compounds and their different chemical structures. Many studies have been done on the flavor of pork and beef meat [22]. In addition, the flavor of cured meat products has also been studied [23], but more attention needs to be paid to the different processing techniques, which affect the flavor formation on cured meat products. In general, there is no clear path that indicates the compounds responsible for the cured meat flavor notes [23]. However, the concentration of carbonyl compounds was higher in uncured pork than in cured meat [24]. Therefore, in this chapter the studies of flavor in each product are presented individually to determine the effects of the different processing technologies.

9.2.1 Bacon

Bacon is manufactured using pork bellies pumped with a curing pickle containing salt, sugar, sodium nitrite, and sodium erythorbate. The pumped bellies are vacuum tumbled, smoked, and then heat processed. Afterwards, the bellies are chilled, sliced, and packaged.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The role of nitrite in cured meat flavor has been widely reviewed [25] because it was questioned due to its involvement in the formation of *N*-nitroso compounds in cured meats. Moreover, bacon is a widely consumed meat product and its acceptability is highly dependent on its flavor. Generally, the flavor volatile compounds have been extracted by distillation [26,27] or by dynamic headspace analysis [28,29]. Hundreds of volatile compounds have been identified in bacon, although the number of compounds extracted depends on the cooking process. Thus, a higher number of compounds (around 150) have been extracted from fried bacon [26,30], 80 from cooked bacon [28,29], and around 40 from bacon without a previous cooking [27]. The chemical classes isolated are indicated in Table 9.1.

Mottram [28] reported qualitative differences between cured and uncured bacon, such as the presence of several unsaturated and aromatic aldehydes in the nitrite free sample and the presence of benzonitrile, phenylacetonitrile, and alkyl nitrates in the cured bacon samples. Later, Mottram et al. [29] reported that the possible origin of these nitrogen compounds was the reaction between fatty acids in the lipids and sodium nitrite. In addition, the aroma of alkylnitrates and alkylnitriles was similar to their corresponding aliphatic aldehydes, and their odor thresholds were relatively high; therefore, they concluded that their contribution to the aroma of cured meats was unimportant.

Ho et al. [26] indicated the impact of each chemical class on bacon flavor; hydrocarbons, alcohols, and carbonyl compounds are probably not primary contributors to the flavor of bacon. Also, a high number of pyrazines were identified, contributing to a roasted nut sensory perception,

Table 9.1 Chemical Compounds Isolated in Bacon

	Number of Identified Compounds				
Chemical Compound	*Ho et al. [26]*	*Timón et al. [30]*	*Ai-Nog and Bao-Guo [27]*	*Mottram et al. [29]*	*Ho et al. [26] (from smoke)*
Hydrocarbons	18	60	9	25	2
Alcohols	16	19	1	12	1
Ketones	11	14	1	9	5
Aldehydes	8	24	1	15	3
Ethers	3				
Esters	7		7		
Acids	4		5		4
Phenols	10		12		8
Pyrazines	22	5		4	4
Furans	12	7		3	6
Thiazoles	3	5		2	
Oxazoles	3				
Pyrroles	6	1			1
Pyridines	4	4		2	
Alkyl nitrates		4		6	

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

whereas furans contributed to a sweet, nutty, and caramel-like odor impression. The thiazols and oxazoles detected in bacon produced a green, nutty, and vegetable-like aroma. However, a high number of phenols were identified, and it is clear that these compounds are derived from the smoke flavor, as indicated in Table 9.1; many of these have been reported in wood smoke vapor.

However, until now there has been only one olfactometry study available on bacon [30]; the main odorants identified are reported in Table 9.2. This study used only one assessor, who described the odors and repeated the analyses several times. In this case, the aldehydes contributed their typical odor notes such as oily, grassy, and rancid, although the meaty characteristic was imparted by pyrazine and furan compounds.

Recent studies on bacon flavor have been focused on those factors that affect the sensory characteristics. This is the case with the study of the effect of pork belly thickness on bacon [31] and the addition of *n-3* polyunsaturated fatty acids on bacon quality [32].

Table 9.2 Main Aroma Compounds Detected in Bacon by GCO

Chemical Group	*Chemical Compound*	*Aroma by GCO*
Aldehydes	Pentanal	Rancid, grassy
	2-Pentenal	Rancid
	Hexanal	Rancid, grassy, oily
	Heptanal	Fruity
	2-Heptenal	Oily
	Octanal	Lemon
	2-Octenal	Rancid, biscuit
	Nonanal	Fruity, fatty
	2-Nonenal	Cooked meat, grassy
	Decanal	Chemical, sweet
	2,4-Nonadienal	Meaty
	2-Decenal	Oily, meaty, rotten
Pyridines	Pyridine	Burnt, rubber
Pyrazine	Methylpyrazine	Meaty
Furan	2-Methyl-(3-methylthio)furan	Meaty
Alcohols	3-Hexen-1-ol	Sweet
	1-Octen-3-ol	Mushroom
Ketones	2-Heptanona	Chemical, bitter

Source: Adapted from Timon, M.L., Carrapiso, A.I., Jurado, A., van de Lagemaat, J., *J. Sci. Food Agr.*, 84, 825–831, 2004.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

9.2.2 Frankfurter

This comminuted product is a complex food system formed by an oil-in-water emulsion. The standard process consists of the preparation of a batter that mostly contains meat (beef, pork, others) and fat, with water, salt, sodium nitrite, sodium ascorbate, polyphosphates, thickeners, and a spice mix. All the ingredients are mixed in a vacuum cutter in different steps to obtain the maximum yield. Once fully mixed, the batter is stuffed, cooked, and, in some cases, smoked.

Many volatile compounds have been identified in frankfurters; for the most part, they have been extracted using headspace techniques, such as purge and trap using Tenax as the adsorbent [33–35] and SPME [36]. The volatile compounds isolated were derived mainly from meat ingredients such as aldehydes, alcohols, ketones, alkanes, and aromatic hydrocarbon, whereas many other compounds were derived from smoke and spices, as the case of phenolic compounds, terpenes, and several sulfur compounds. Few reports have studied the odor activity of the isolated volatile compounds [33]. Odor assessment by olfactometry was done by four assessors who described the odor eluted from the column. They indicated that the compounds derived from the smoke, such as phenols, produced an important contribution to the aroma, whereas the meaty, roasted, and grilled notes were produced by sulfur-containing compounds. Finally, they found the various sulfur compounds can be generated during the cooking process [33].

9.2.3 Cooked Ham

Cooked ham is produced using the pork leg cleaned of skin, bones, connective and adipose tissues, and zones not attractive to consumers. The hams are injected with a brine containing salt, sugar, nitrite or nitrate, ascorbate or erythorbate, aromas, and in some cases polyphoshates and other authorized additives. Once injected, the hams are tumbled, vacuum packaged, and cooked to stabilize the product and to develop the sensory characteristics, coagulated texture, and flavor.

Several reports have studied the volatile composition of cooked ham by simultaneous steam distillation-extraction [37,38] and vacuum distillation [39]; however, only Guillard et al. [39] determined the odor active compounds in cooked ham. Many of the volatile compounds isolated from this product are derived from smoke and seasonings, whereas others come from reactions occurring in the meat. In general, the identified compounds were aldehydes, alcohols, ketones, furans, sulfur compounds, esters, and phenols derived from the smoke, as indicated earlier for bacon. However, the main odorants identified in cooked ham by olfactometry are sulfur compounds such as methional, dimethyl disulfide, and allyl isothiocyanate; acids such as 3-methylbutanoic acid; and compounds derived from spices, such as terpenes. These compounds were identified by three assessors who repeated the analysis twice. In summary, the technique used in olfactometry analysis was only the source for description of the aroma and the number of times it was detected; in general, this corresponds to the technique called detection frequency [20].

9.2.4 Roast Beef

Only a reduced number of beef cuts are manufactured into meat products in comparison to pork or chicken because of the high cost of beef [40]. The roast beef process consists of injecting or immersing the roast cuts in a brine containing salt, sugar, polyphosphates, and occasionally other additives such as sodium nitrite, garlic, and others. After injection the roast cuts can be tumbled, vacuum packaged, and cooked. The flavor characteristics are developed during the cooking process, but the final flavor also depends on the additives added in the brine. There are few reports

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

about the flavor of cured beef; only Ramarathnam et al. [23] studied the difference in volatile compound composition of cured and uncured beef, reporting the presence of 31 hydrocarbons, 26 carbonyls, 3 alcohols, and 2 acids. They reported a lower carbonyl compound concentration in the cured beef, as was also detected in cured pork meat.

9.3 Flavor of Dry-Cured Meat Products

9.3.1 Dry-Cured Ham

The dry-cured ham process is generally very long and significantly affects the final quality of the product. The process consists of different stages: salting, in which the salt containing nitrite and nitrate is rubbed onto the surface and hams are maintained at refrigeration temperatures; postsalting, in which the hams are cleaned of the salt and kept at refrigeration temperatures for salt equalization or distribution; and finally, drying/ripening, in which the temperature of the chambers is progressively increased, while the relative humidity is decreased to dry the hams and develop the flavor.

Approximately 240 volatile compounds have been identified in dry-cured hams [41]; however, the use of different extraction techniques has shown differences among the studies. Several authors have employed dynamic headspace analysis for the extraction of volatile compounds [42–48], whereas others have used vacuum distillation [49,50]. A higher number of carboxylic acids, lactones, and aliphatic hydrocarbons were extracted when vacuum distillation was used than in extraction by dynamic headspace. Most recently, the use of the SPME technique has allowed the extraction of a high number of volatile compounds from dry-cured ham [51–53].

Only a few studies have determined the odor impact of the volatile compounds detected in dry-cured ham [41,47,48,54]. The number of volatile compounds from each chemical class identified in dry-cured ham is reported in Table 9.3. Table 9.3 also includes the volatile compounds that showed an odor property. It is observed that although a high number of hydrocarbons were identified in dry-cured ham, they do not contribute to any odor character, whereas the contribution of aldehydes, alcohols, ketones, and so on was important. The most important group that produces meaty notes are the sulfur compounds; however, there is no specific compound that possesses the characteristic cured aroma.

The olfactometry techniques used for identification of aroma compounds are the description of the aroma by several assessors [41] and the detection frequency method [47,48,54], in which the intensity of the aroma is defined as the number of times that an odor is detected by the assessors. In these analyses, several sulfur compounds (methanethiol and 2-methyl-3-furanthiol) showed the highest detection frequency values together with several aldehydes (3-methyl-butanal and hexanal). Also, many other volatile compounds contributed to the odor of the dry-cured ham, as shown in Table 9.3.

9.3.2 Dry-Fermented Sausages

Dry-fermented sausages are manufactured by mixing minced meat and additives (salt, sugar, nitrite and nitrate, ascorbate, spices, and others) and then stuffing them into casings. Then the sausages are allowed to ferment and dry to develop their organoleptic characteristics.

Many volatile compounds have been identified in dry-fermented sausages using different extraction techniques. Dynamic headspace analysis has been used many times, yielding a large number

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 9.3 Chemical Compounds Isolated from Dry-Cured Ham and the Main Odorants Reported by GCO

Group of Compounds	*Number of Compounds*[b]	*Compounds*	*Odor*[a]
Aldehydes	48	2-methyl-propanal	Fruity, pungent
		3-methyl-butanal	Fruity, almond like
		Hexanal	Green
		(E)-2-hexenal	Fruity, green
		(Z)-3-hexenal	Fruity
		(E)-2-nonenal	Fatty, leather-like
Alcohols	41	1-Octen-3-ol	Mushroom
		1-Pente-3-ol	Onion, toasted
Hydrocarbons	48	—	—
Sulfur compounds	7	2-Methyl-3-furanthiol	Cured-ham like
		Methanethiol	Toasted
		Hydrogen sulfide	Rotten eggs, meat
		Methional	Boiled eggs, sewage
		Dimethyl disulfide	Dirty socks
Ketones	24	2-Heptanone	Nutty
		1-Penten-3-one	Rotten, fruity
		2,3-Butanedione	Buttery
		3-Hydroxy-2-butanone	Fruit red jello
		2-Hexanone	Floral, apple
Esters	38	Ethyl-2-methylbutanoate	Fruity, apple like
		Methyl butanoato	Sweet caramel
Pyrazines	4	Methylpyrazine	Nutty
		2,6-Dimethyl-pyrazine	Toasted nuts
Lactones	7		
Acids	18	Acetic acid	Vinegar
Furans	5	2,5-Dimethyl furan 2-Pentyl furan	Sulfury, fishy Ham-like
Pyrrol	2	2-Acetyl-1-pyrroline Pyrrol	Roasty, popcorn Meaty

[a] Odor detected by assessors in Refs 46–48, 54.
[b] Number of compounds identified in Refs 46–48, 54.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 9.4 Odor-Active Compounds Identified in the Headspace of Fermented Sausages

Number[a]	*GCO Descriptor*	*Compounds*	*N*[a]	*GCO Descriptor*	*Compounds*
1	Acetone, alcohol	Acetone	29	Meat broth, rancid, savory snack	Methional (3-methylthio-propanal)
2	Rotten eggs, cauliflower	Methanethiol	30	Rotten, strawberry, sweet	Unknown (2)
3	Bread dough, yeast	Ethanol	31	Onions, savory, rancid	2-Pentylfuran
4	Sweet, snacks	Butanal	32	Rancid, dirty	2-Heptenal (E)
5	Cheese, snacks	Diacetyl (2,3-butanedione)	33	Mushroom	1-Octen-3-ol
6	Fruity, toffees	Ethyl acetate	34	Sweet, fruity, cherry	Ethyl hexanoate
7	Rancid, dry-cured ham	3-Methylbutanal	35	Geranium, herbal, floral	Octanal
8	Vinegar	Acetic acid	36	Citrus, orange	Limonene
9	Toasted, garlic	2-Ethylfuran	37	Roasted, butter, soap	2,4-Heptadienal
10	Roasted, sweet	2-Pentanone	38	Cooked meat, nutty	2,4-Heptadienal (E,E)
11	Fresh cut grass, rancid	Pentanal	39	Roses	Phenylacetaldehyde
12	Butter, cheese	2,3-Pentanedione	40	Dry-cured ham, dry-cured sausage	2-Octenal (E)
13	Strawberry	Ethyl 2-methylpropanoate	41	Rancid nuts, woody	Unknown (3)
14	Cheese	Propanoic acid	42	Mushroom	1-Octanol
15	Roasted, roasted meat	1-Pentanol	43	Roasted, burnt	2-Nonanone
16	Fresh-cut grass, rancid	Hexanal	44	Plastic, soap	Nonanal
17	Strawberry	Ethyl butanoate	45	Waxy, smoke	Unknown (4)
18	Fatty, savory snacks	2-Methylpropanoic acid	46	Green, fresh	Unknown (5)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 9.4 (continued) Odor-Active Compounds Identified in the Headspace of Fermented Sausages

Number[a]	*GCO Descriptor*	*Compounds*	*N*[a]	*GCO Descriptor*	*Compounds*
19	Strawberry	Ethyl 2-methylbutanoate	47	Rotten cheese, rotten orange	Unknown (6)
20	Cheese	Butanoic acid	48	Rancid, dry-cured ham	Heptanoic acid
21	Salty meat, dry-cured ham	2-Hexenal (E)	49	Roasted nuts, fried snacks	Unknown (7)
22	Green grass, plastic	1-Hexanol	50	Burnt plastic, stable	Unknown (8)
23	Strawberry	Ethyl pentanoate	51	Winery	Phenylethyl alcohol
24	Cheese, feet, dirty socks	3-Methylbutanoic acid	52	Plastic, salty, rancid	Unknown (9)
25	Medicinal, fruity	2-Heptanone	53	Herbal, crushed leaves	Unknown (10)
26	Citrus, soap, rancid cured ham	Heptanal	54	Cucumbers, herbal, woody	2-Nonenal (E)
27	Plastic, pork scratchings	2-Heptanol	55	Rancid, woody	Octanoic acid
28	Roasted nuts, fried snacks	Unknown (1)			

Source: Adapted from Marco, A., Navarro, J.L., Flores, M., *J Agr. Food Chem*., 55, 3058–3065, 2007.
[a] Number of the aroma in order of chromatographic elution and in accordance with Figure 9.3.

of volatile compounds [55–64]. In addition, distillation techniques have been used [65–68], giving similar results, but this technique allows the extraction of a higher number of high-boiling and sulfur compounds than do headspace techniques. In recent years, the use of SPME has been applied and many volatile compounds were extracted; however, the nature of the volatile compounds extracted depended on the fiber used [69–72].

The contribution of volatile compounds to the aroma of dry-fermented sausages has been studied using olfactometry techniques. The first studies on dry-fermented aroma used the description of the aroma eluted from the gas chromatograph [57,64]. Then other studies used the AEDA technique to select the flavor DF of each odor compound [65–68]. Authors reported that the greatest contribution to aroma was due to sulfur compounds derived from spices such as garlic, but also to acids, 3-methyl-butanoic and acetic acids, methional, and 2-acetyl-pyrroline.

Recent studies on the aroma of dry-fermented sausages showed the contribution of a large number of different chemical compounds (Table 9.4), alcohols, esters, acids, aldehydes, etc. [73].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

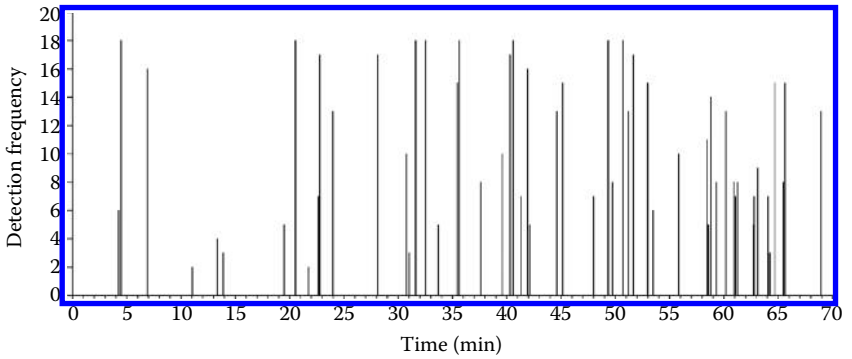


Figure 9.3 Detection frequency signal of a dry-fermented sausage obtained from the olfactometry detector using six assessors.

The contribution of each volatile compound to the aroma of the dry-fermented sausage was determined by the detection frequency method (Figure 9.3). In this study the authors reported that the high concentration of compounds such as 1-octen-3-ol, hexanal, and heptanal would be important contributors to the aroma because their concentrations were above their detection thresholds.

In summary, the content of volatile compounds in dry-fermented sausages depends on the process due to the considerable differences among northern and southern European cured products [4]. Therefore, the contribution of each volatile compound to the aroma of the food product should be carefully evaluated.

References

1. Flores, J., Toldrá, F. Curing: Processes and applications. In: *Encyclopedia of Food Science, Food Technology and Nutrition,* R. Macrae, R. Robinson, M. Sadle, G. Fullerlove, Eds., Academic Press, London, pp. 1277–1282, 1993.
2. Chen, J., Ho, C.T. The flavour of pork. In: *Flavor of Meat, Meat Products and Seafoods*, F. Shahidi, Ed., Blackie Academic & Professional, London, pp. 61–81, 1998.
3. Shahidi, F. Flavour of muscle foods. In: *Flavor of Meat, Meat Products and Seafoods*, F. Shahidi, Ed., Blackie Academic & Professional, London, pp. 1–4, 1998.
4. Toldrá, F., Flores, M. Processed pork meat flavors (Chap. 61). In: *Handbook of Food Products Manufacturing*, Y.H. Hui, Ed., Wiley, New York, pp. 281–301, 2007.
5. Parliament, T.H. Solvent extraction and distillation techniques. In: *Techniques for Analyzing Food Aroma*, R. Marsili, Ed., Marcel Dekker, New York, pp. 1–26, 1997.
6. Marsili, R. *Techniques for Analyzing Food Aroma*, Marcel Dekker, New York, 1997.
7. Cadwallader, K.R., MacLeod, A.J. Instrumental methods for analyzing the flavor of muscle foods. In: *Flavor of Meat, Meat Products and Seafoods,* F. Shahidi, Ed., Blackie Academic & Professional, London, pp. 320–341, 1998.
8. Whampler, T. Analysis of food volatiles using headspace-gas chromatographic techniques. In: *Techniques for Analyzing Food Aroma*, R. Marsili, Ed., Marcel Dekker, New York, pp. 27–58, 1997.
9. Harmon, A.D. Solid phase microextraction for the analysis of flavors. In: *Techniques for Analyzing Food Aroma*, R. Marsili, Ed., Marcel Dekker, New York, pp. 81–112, 1997.
10. Grimm, C.C., Lloyd, S.W., Miller, J.A., Spanier, A.M. The analysis of food volatiles using direct thermal desorption. In: *Techniques for Analyzing Food Aroma*, R. Marsili, Ed., Marcel Dekker, New York, pp. 59–80, 1997.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

11. Blank, I. Gas chromatography olfactometry in food aroma analysis. In: *Techniques for Analyzing Food Aroma*, R. Marsili, Ed., Marcel Dekker, New York, pp. 293–330, 1997.
12. Ulrich, F., Grosch, W. Identification of the most intense volatile flavour compounds formed during autoxidation of linoleic acid. *Z. Lebensm. Unters. For.* 184:277–282, 1987.
13. Grosch, W. Detection of potent odorants in foods by aroma extract dilution analysis. *Trend. Food Sci. Tech.* 4:68–73, 1993.
14. Kerscher, R., Grosch, W. Comparative evaluation of potent odorants of boiled beef by aroma extract dilution and concentration analysis. *Z. Lebensm. Unters. F. A* 204:3–6, 1997.
15. Zehentbauer, G., Reineccius, G.A. Determination of key aroma compounds of cheddar cheese using dynamic headspace dilution assay. *Flavour Frag. J.* 17:300–305, 2002.
16. Acree, T.E., Barnard, J., Cunningham, D.G. A procedure for the sensory analysis of gas chromatographic effluents. *Food Chem.* 14:273–286, 1984.
17. Cunningham, D.G., Acree, T.E., Barnard, J., Butts, R.M., Braell, P.A. Charm analysis of apple volatiles. *Food Chem.* 19:137–147, 1986.
18. Miranda-Lopez, R., Libbey, L.M., Watson, B.T., McDaniel, M.R. Odor analysis of pinot noir wines from grapes of different maturities by gas-chromatography-olfactometry technique (Osme). *J. Food Sci.* 57:985–993, 1019, 1992.
19. Etiévant, P.X., Callement, G., Langlois, D., Issanchou, S., Coquibus, N. Odor intensity evaluation in gas chromatography-olfactometry by finger span method. *J. Agr. Food Chem.* 47:1673–1680, 1999.
20. Linssen, J.P.H., Janssens, J.L.G.M., Roozen, J.P., Posthumus, M.A. Combined gas chromatography and sniffing port analysis of volatile compounds of mineral water packed in polyethylene laminated packages. *Food Chem.* 46:367–371, 1993.
21. Pollien, P., Ott, A., Montigon, F., Baumgartner, M., Muñoz-Box, R., Chaintreau, A. Hyphenated headspace-gas chromatography sniffing technique: screening of impact odorants and quantitative aromagram comparisons. *J. Agr. Food Chem.* 45:2630–2637, 1997.
22. Macleod, G. The flavour of beef. In: *Flavor of Meat, Meat Products and Seafoods*, F. Shahidi, Ed., Blackie Academic & Professional, London, pp. 28–56, 1998.
23. Ramarathnam, N. Flavor of cured meat. In: *Flavor of Meat, Meat Products and Seafoods*, F. Shahidi, Ed., Blackie Academic & Professional, London, pp. 290–319, 1998.
24. Ramarathnam, N., Rubin, L.J., Diosady, L.L. Studies on meat flavor. 1. Qualitative and quantitative differences in uncured and cured pork. *J. Agr. Food Chem.* 39:344–350, 1991.
25. Gray, J.I., MacDonald, B., Pearson, A.M., Morton, I.D. Role of nitrite in cured meat flavor. *J. Food Prot.* 44:302–312, 1981.
26. Ho, C.T., Lee, K.N., Jin, Q.Z. Isolation and identification of volatile flavor compounds in fried bacon. *J. Agr. Food Chem.* 31:336–342, 1983.
27. Ai-Nong, Y., Bao-Guo, S. Flavor substances of Chinese traditional smoke-cured bacon. *Food Chem.* 89:227–233, 2005.
28. Mottram, D.S. Organic nitrates and nitriles in the volatiles of cooked cured pork. *J. Agr. Food Chem.* 32:343–345, 1984.
29. Mottram, D.S., Croft, S.E., Patterson, R.L.S. Volatile components of cured and uncured pork: The role of nitrite and the formation of nitrogen compounds. *J. Sci. Food Agr.* 35:233–239, 1984.
30. Timon, M.L., Carrapiso, A.I., Jurado, A., van de Lagemaat, J. A study of the aroma of fried bacon and fried pork loin. *J. Sci. Food Agr.* 84:825–831, 2004.
31. Person, R.C., McKenna, D.R., Griffin, D.B., McKeith, F.K., Scanga, J.A., Belk, K.E., Smith, G.C., Savell, J.W. Benchmarking value in the pork supply chain: Processing characteristics and consumer evaluations of pork bellies of different thickness when manufactures into bacon. *Meat Sci.* 70:121–131, 2005.
32. Sheard, P.R., Enser, M., Wood, J.D., Nute, G.R., Gill, B.P., Richardson, R.I. Shelf life and quality of pork and pork products with raised n-3 PUFA. *Meat Sci.* 55:213–221, 2000.
33. Chevance, F.F.V., Farmer, L.J. Identification of major volatile odor compounds in frankfurters. *J. Agr. Food Chem.* 47:5151–5160, 1999.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

34. Chevance, F.F.V., Farmer, L.J., Desmond, E.M., Novelli, E., Troy, D.J., Chizzolini, R. Effect of some fat replacers on the release of volatile aroma compounds from low-fat meat products. *J. Agr. Food Chem*. 48:3476–3484, 2000.
35. Chevance, F.F.V., Farmer, L.J. Release of volatile odor compounds from full-fat and reduced-fat frankfurters. *J. Agr. Food Chem*. 47:5161–5168, 1999.
36. Estevez, M., Ventanas, S., Ramirez, R., Cava, R. Influence of the addition of rosemary essential oil on the volatiles pattern of porcine frankfurters. *J. Agr. Food Chem*. 53:8317–8324, 2005.
37. Baloga, D.W., Reineccius, G.A., Miller, J.W. Characterization of ham flavor using an atomic emission detector. *J. Agr. Food Chem*. 38:2021–2026, 1990.
38. DeWinne, A., Dirinck, P. Studies on vitamin E and meat quality. 3. Effect of feeding high vitamin E levels to pigs on the sensory and keeping quality of cooked ham. *J. Agr. Food Chem*. 45:4309–4317, 1997.
39. Guillard, A.S., LeQuere, J.L., Vendeuvre, J.L. Emerging research approaches benefit to the study of cooked cured ham flavour. *Food Chem*. 59:567–572, 1997.
40. Boles, J.A., Swan, J.E., Processing and sensory characteristics of cooked roast beef: effect of breed, age, gender and storage conditions. *Meat Sci*. 62:419–427, 2002.
41. Flores, M., Spanier, A.M., Toldrá, F. Flavour analysis of dry-cured ham. In: *Flavor of Meat, Meat Products & Seafood*, F. Shahidi, Ed., 2nd ed., Blackie Academic & Professional, London, pp. 320–341, 1998.
42. Hinrichsen, L.L., Pedersen, S.B. Relationship among flavor, volatile compounds, chemical-changes, and microflora in Italian-type dry-cured ham during processing. *J. Agr. Food Chem*. 43:2932–2940, 1995.
43. Barbieri, G., Bolzoni, L., Parolari, G., Virgili, R., Buttini, R., Careri, M., Mangia, A. Flavor compounds of dry-cured ham. *J. Agr. Food Chem*. 40:2389–2394, 1992.
44. Buscailhon, S., Berdagué, J.L., Bousset, J., Cornet, M., Gandemer, G., Touraille, C., Monin, G. Relations between compositional traits and sensory qualities of French dry-cured ham. *Meat Sci*. 37:229–243, 1994.
45. Bolzoni, L., Barbieri, G., Virgili, R. Changes in volatile compounds of Parma ham during maturation. *Meat Sci*. 43:301–310, 1996.
46. Flores, M., Grimm, C.C., Toldrá, F., Spanier, A.M. Correlations of sensory and volatile compounds of Spanish "Serrano" dry-cured ham as a function of two processing times. *J. Agr. Food Chem*. 45:2178–2186, 1997.
47. Carrapiso, A.I., Jurado, A., Timon, M.L., García, C. Odor-active compounds of Iberian hams with different aroma characteristics. *J. Agr. Food Chem*. 50:6453–6458, 2002.
48. Carrapiso, A.I., Ventanas, J., García, C. Characterization of the most odor-active compounds of Iberian ham headspace. *J. Agr. Food Chem*. 50:1996–2000, 2002.
49. García-Esteban, M., Ansorena, D., Astiasaran, I., Martin, D., Ruiz, J. Comparison of simultaneous distillation extraction (SDE) and solid-phase microextraction (SPME) for the analysis of volatile compounds in dry-cured ham. *J. Sci. Food Agr*. 84:1364–1370, 2004.
50. Berdagué, J.L., Denoyer, C., LeQueré, J.L., Semon, E. Volatile components of dry-cured ham. *J. Agr. Food Chem*. 39:1257–1261, 1991.
51. Ruiz, J., Cava, R., Ventanas, J., Jensen, M.T. Headspace solid phase microextraction for the analysis of volatiles in a meat product: Dry-cured Iberian ham. *J. Agr. Food Chem*. 46:4688–4694, 1998.
52. Gianelli, M.P., Flores, M., Toldrá, F. Optimisation of solid phase microextraction (SPME) for the analysis of volatile compounds in dry-cured ham. *J. Sci. Food Agr*. 82:1703–1709, 2002.
53. García-Esteban, A., Ansorena, D., Astiasaran, I., Ruiz, J. Study of the effect of different fiber coatings and extraction conditions on dry cured ham volatile compounds extracted by solid-phase microextraction (SPME). *Talanta* 64:458–466, 2004.
54. Carrapiso, A.I., García, C. Iberian ham headspace: Odorants of intermuscular fat and differences with lean. *J. Sci. Food Agr*. 84:2047–2051, 2004.
55. Berdagué, J.L., Monteil, P., Montel, M.C., Talon, R. Effects of starter cultures on the formation of flavor compounds in dry sausage. *Meat Sci*. 35:275–287, 1993.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

56. Viallon, C., Berdagué, J.L., Montel, M.C., Talon, R., Martín, J.F., Kondjoyan, N., Denoyer, C. The effect of stage of ripening and packaging on volatile content and flavour of dry sausage. *Food Res. Int*. 29:667–674, 1996.
57. Stahnke, L.H. Aroma components from dried sausages fermented with *Staphylococcus xylosus*. *Meat Sci*. 38:39–53, 1994.
58. Stahnke, L.H. Dried sausages fermented with *Staphylococcus xylosus* at different temperatures and with different ingredient levels. 2. Volatile components. *Meat Sci*. 41:193–209, 1995.
59. Stahnke, L.H. Volatiles produced by *Staphylococcus xylosus* and *Staphylococcus carnosus* during growth in sausage minces—Part I. Collection and identification. *Food Sci. Technol. Leb*. 32:357–364, 1999.
60. Edwards, R.A., Ordoñez, J.A., Dainty, R.H., Hierro, E.M., de la Hoz, L. Characterization of the headspace volatile compounds of selected Spanish dry fermented sausages. *Food Chem*. 64:461–465, 1999.
61. Sunesen, L.O., Dorigoni, V., Zanardi, E., Stahnke, L. Volatile compounds released during ripening in Italian dried sausage. *Meat Sci*. 58:93–97, 2001.
62. Bruna, J.M., Hierro, E.M., de la Hoz, L., Mottram, D.S., Fernández, M., Ordóñez, J.A. The contribution of *Penicillium aurantiogriseum* to the volatile composition and sensory quality of dry fermented sausages. *Meat Sci*. 59:97–107, 2001.
63. Bruna, J.M., Fernández, M., Hierro, E.M., Ordonez, J.A., de la Hoz, L. Improvement of the sensory properties of dry fermented sausages by the superficial inoculation and/or the addition of intracellular extracts of *Mucor racemosus*. *J. Food Sci*. 65:731–738, 2000.
64. Meynier, A., Novelli, E., Chizzolini, R., Zanardi, E., Gandemer, G. Volatile compounds of commercial Milano salami. *Meat Sci*. 51:175–183, 1999.
65. Schmidt, S., Berger, R.G. Microbially formed aroma compounds during the maturation of dry fermented sausage (salami). *Adv. Food Sci*. 20:144–152, 1998.
66. Schmidt, S., Berger, R. Aroma compounds in fermented sausages of different origins. *Food Sci. Technol. Leb*., 31:559–567, 1998.
67. Blank, I., Devaud, S., Fay, L.B., Cerny, C., Steiner, M., Zurbriggen, B. Odor-active compounds of dry-cured meat: Italian-type salami and Parma ham. In: *Aroma-Active Compounds in Foods. Chemistry and Sensory Properties*, G.R. Takeoka, M. Güntert, K.H. Engel, Eds., American Chemical Society, Washington, pp. 9–20, 2001.
68. Berger, R.G., Macku, C., German, J.B., Shibamoto, T. Isolation and identification of dry salami volatiles. *J. Food Sci*. 55:1239–1242, 1990.
69. Marco, A., Navarro, J.L., Flores, M. Volatile compounds of dry-fermented sausages as affected by solid-phase microextraction (SPME). *Food Chem*. 84:633–641, 2004.
70. Marco, A., Navarro, J.L., Flores, M. The influence of nitrite and nitrate in microbial, chemical and sensory parameters of slow dry fermented sausage. *Meat Sci*. 73:660–673, 2006.
71. Marco, A., Navarro, J.L., Flores, M. The quality of dry fermented sausages as affected by fermentation stage and curing agents. *Eur. Food Res. Technol*. 226: 449–458, 2008.
72. Durá, M.A., Flores, M., Toldrá, F. Effect of *Debaryomyces* spp on aroma formation and sensory quality of dry-fermented sausages. *Meat Sci*. 68:439–446, 2004.
73. Marco, A., Navarro, J.L., Flores, M. Quantitation of selected odor-active volatile constituents in dry fermented sausages prepared with different curing salts. *J. Agr. Food Chem*. 55:3058–3065, 2007.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 10

Sensory Descriptors for Cooked Meat Products

Jenny E. Hayes

Contents

10.1 Introduction 148
10.2 Methods of Descriptive Analysis 148
10.2.1 Flavor Profile 148
10.2.2 Texture Profile 149
10.2.3 The Spectrum™ Descriptive Analysis Method 150
10.2.4 The Quantitative Descriptive Analysis Method 150
10.2.5 Quantitative Flavor Profiling 151
10.2.6 Generic Descriptive Analysis 151
10.2.7 Free Choice Profiling 151
10.3 Panel Selection 152
10.4 Descriptor Development 153
10.5 Meat Texture Descriptors 153
10.6 Meat Flavor Descriptors 158
10.6.1 Mouthfeel Characteristics in Meat Products 160
10.6.2 Lipid Oxidation and Warmed-Over Flavor in Meat Products 161
10.6.3 Boar/Sex Taint 162
10.6.4 Flavor Lexicons 162
10.7 Odor in Meat Products 164
10.8 Conclusions 165
References 165

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

10.1 Introduction

The flavor and texture of a food product are determined by its components (character notes) and the arrangement (order of appearance) and the intensity of these components. Sensory analysis is the analysis of product attributes perceived by the human senses of touch, smell, sight, taste, and hearing. Descriptive analysis is a sensory method that provides quantitative and qualitative descriptions[1] of products, based on their perceptions by a group of qualified assessors. Trained descriptive panels should not be asked to evaluate flavor or any other attribute in terms of like/dislike or acceptability; these responses should be obtained only from a consumer panel.[2] The qualitative aspects of a product include all aroma, appearance, flavor, texture, mouth feel (aftertaste), and sound properties of the product which distinguish it from others. The sensory assessor then quantifies these product attributes to facilitate description and intensity of the perceived product attributes.

Descriptive analysis of any food requires a descriptive technique and a lexicon or language to describe the sensory properties. A group or family of attributes (lexicon) describes specific sensory attributes in products that can be used to evaluate development or change in these attributes. The results from descriptive analysis tests provide complete sensory descriptions of the products, provide the basis for mapping product differences and similarities, and provide a basis for determining those sensory attributes that are most important for acceptance. In many cases descriptive analysis can be used as a method to provide information that cannot be obtained by other analytical means. For example, the analysis of lipid oxidation does not indicate how rancid a meat product tastes or the level or intensity of off-flavors present. It is also very difficult to monitor subtle changes in shelf life or package stability using analytical instrumentation. The only useful way to monitor complex changes in lipid oxidation, rancidity or flavor intensity, as well as the inclusion of new descriptors that may often occur during the storage of meat products, is by using descriptive analysis methods. This chapter will outline the various descriptive sensory analysis methods, panel selection, and approaches to descriptor development related specifically to cooked meat products and possible examples of where different descriptors have been used in meat product research.

10.2 Methods of Descriptive Analysis

10.2.1 Flavor Profile

The Flavor Profile Method (FPM) was introduced by Arthur D. Little Inc., in 1949 and is the only formal qualitative descriptive procedure.[3–5] It is based on the idea that flavor consists of identifiable taste, odor, and chemical feeling factors plus an underlying complex of sensory impressions not separately identifiable. The FMP utilizes a panel of four to six panelists who are screened for sensory acuity, that is, normal abilities to smell and taste, including odor perception, odor recognition, and taste sensitivity.[3] During training the panel is instructed to precisely define the flavors of the product category. The panel is exposed to a wide range of samples in the product category, and during training panelists evaluate and refine the flavor vocabulary. A good prospective flavor panelist should be able to discriminate between taste and aroma sensations.[6] The panel leader is a member of the panel, is a key member of the group, and works with them to generate the language and the method for sample preparation and evaluation. Panel members consider aspects of overall flavor and the detectable flavor components of foods. The scale used for each descriptor is a 4-point scale (0 = not present, 1 = slight, 2 = moderate, 3 = strong). This scale is further refined into half units to show narrower ranges. The key components of the flavor profile are amplitude, identification of perceptible aroma and flavor notes, the intensity and order of appearance of each character note,

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and any aftertaste sensations. A disadvantage of FPM is that due to the small number of highly trained experts, the absence of one panel member can have a severe impact on the sensory program. However, the amount of work in running FPM is usually less due to this small number, and the panel is very cohesive in comparison to a Quantitative Descriptive Analysis (QDA) panel.[7]

10.2.2 Texture Profile

In 1963, the Textural Profile Method (TPM) was developed at the General Foods Research Center.[8–10] Brant et al.[8] defined the Textural Profile as "the sensory analysis of the texture complex of a food in terms of its mechanical, geometrical, fat and moisture characteristics, the degree of each present and the order in which they appear from the first bite through to complete mastication." The development of the texture profile method was based on the adaptation of rheological principles to sensory evaluation and on the overall concept of the FMP. Attributes are defined to describe texture from initial bite to residual sensations remaining after swallowing. Terminology and references were developed to illustrate various classifications of textural characteristics. Following classification, the various texture attributes (or parameters) can be grouped into three main categories: mechanical characteristics, geometrical characteristics, and fat and moisture content (Table 10.1).

Table 10.1 Relationship between Textural Properties and Popular Nomenclature

Primary Parameters	*Secondary Parameters*	*Popular Terms*
Mechanical Characteristics		
Hardness		Soft, firm, hard
Cohesiveness	Brittleness	Crumbly, crunchy, brittle
	Chewiness	Tender, chew, tough
	Gumminess	Short, mealy, pasty, gummy
Viscosity		Thin, viscous
Elasticity		Plastic, elastic
Adhesiveness		Sticky, tacky, gooey
Geometrical Characteristics		
Class		*Examples*
Particle shape and size		Gritty, grainy, coarse, etc.
Particle shape and orientation		Fibrous, cellular, crystalline, etc.
Other Characteristics		
Moisture content		Dry, moist, wet, watery
Fat content	Oiliness	Oily
	Greasiness	Greasy

Source: Reproduced from Szczesniak, A.S., *J. Food Sci.*, 28, 385–389, 1963.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Mechanical characteristics deal with the resistance to breakdown and have primary parameters. Geometrical characteristics deal with the (a) particle size and shape of particles and (b) particle shape and orientation. Fat and moisture content and the rate and manner of their release are related to mouth feel. Screening procedures are conducted to eliminate candidates with dentures and those who are unable to discriminate between and describe texture differences.[11] The original TPM used expanded 13-point scales, however;[10] TPM panels have recently been trained using category, line, and magnitude estimation scales.[4] Jeremiah et al.[12] stated that the dimensions of the profile method (i.e., flavor and texture) include: (a) character notes of perceptible aroma, flavor, and texture factors; (b) degree of intensity of each factor; (c) the order in which these factors are perceived; (d) aftertastes or after feelings; and (e) amplitude or overall impression.

10.2.3 The Spectrum™ Descriptive Analysis Method

The Spectrum Descriptive Analysis Method, a universal intensity method, provides a complete, detailed, and accurate descriptive characterization of a product's sensory attributes.[1,13] The Spectrum examines the complete "spectrum" of product attributes. This method emphasizes both qualitative and quantitative aspects of descriptive measurement; that is, the Spectrum panel describes the sensory language of the product in detail (characteristics of flavor and texture) and order of appearance. It is a descriptive attribute method that uses a 0–15 point universal scale, where 0 = none and 15 = extremely intense, to evaluate the sensory attributes of foods. The specific attributes of a product or attributes of interest are identified through ballot development sessions or using a standard lexicon. By examining a wide range of products within the category, panelists develop their list of attributes. The method provides an array, or lexicon, of standard attribute names, each with a set of standards that define the scale of intensity. The scales used in the Spectrum method are based on wide use of reference points along their range that correspond to food reference samples. It is reported that the use of these points may reduce panelist variability, which allows for better correlations with other data—for example, instrumental data.[14] Results are usually graphically represented using histograms. Johnsen and Civille[15] successfully applied the Spectrum method, developing a standard lexicon of meat warmed-over flavor (WOF) descriptors. Several other published studies have been carried out on pork and chicken, and many other studies use the principles applied by this method in descriptive sensory analysis.[16,17]

10.2.4 The Quantitative Descriptive Analysis Method

The method of QDA is based on the principle of a panelist's ability to verbalize perceptions of a product.[18–20] The method represents a formal screening and training of panelists, development and use of sensory terminology, and scoring of products to obtain a complete quantitative description. The panel leader is a sensory professional who acts as a facilitator but does not participate as a panelist, coordinating the training and screening of panelists. The order of appearance of the attributes and the order of assessment of the sensory descriptors is also determined by the panel. Definitions of the sensory descriptors are generated, which can further clarify the descriptors. The method uses a continuous 15-cm line scale anchored at each end to quantitate each sensory attribute. The data can be analyzed statistically and is reported graphically in the form of a web plot where a branch from the center point in the web represents the intensity of that attribute. QDA has been carried out in numerous studies with a variety of meat products, including beef,[21,22] cooked ham and dry-cured ham,[23] dry-cured sausages,[24] and pork.[25]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

10.2.5 Quantitative Flavor Profiling

The Quantitative Flavor Profiling (QFP) method was developed by Givaudan-Roure, Switzerland[26–28] and is a modification of the QDA technique.[18] QDA profiles all sensory attributes of a product, whereas QFP concentrates solely on the flavor attributes of the product. The language used in QFP is technical; a supposed advantage of this method is that no invalid terms will be included, as the flavorists have a wide technical knowledge. QFP is characterized by the development of a standardized flavor language (flavor descriptors and physical references) and the quantification of selected flavor characteristics. QFP depends largely on the set of reference standards and a common standardized flavor language to demonstrate concepts and intensity. The use of reference standards plays an important role in the development of appropriate flavor terminology and also reduces the amount of time required to train sensory panelists, while providing documentation for terminology. Stampanoni[26] focuses on the quantification of flavor characteristics for ham and bacon using QFP.

10.2.6 Generic Descriptive Analysis

Many organizations require the use of generic descriptive analysis, which allows the most suitable philosophies of various methods to be used and combined according to the project requirements (e.g., Lawless and Heymann,[5] Jahan et al.,[29] Veberg et al.[30]).

10.2.7 Free Choice Profiling

Free Choice Profiling (FCP), developed by Williams and Arnold,[31] involves no screening or training but allows the assessors to develop their own descriptive terms; yet panelists must be able to detect differences between samples, verbally describe the perceived attributes, and quantitate them.[32] Assessors should be guided in their description with advice to provide descriptors under the headings "appearance," "texture," "odor," and "flavor." The data is analyzed by General Procrustes Analysis (GPA), a multivariant technique which adjusts for the use of different parts of the scale by different panelists and then manipulates the data to combine descriptors that appear to measure the same parameter.[33] As a result, GPA allows for individual variation in descriptors of the panelists to be examined by correlating them with principal axes of the centroid of the assessor sample spaces.[34] When developing free-choice profiling for muscle foods, it is desirable to provide a range of the product type—for example, different textural properties or variety of off-flavors—and to use a sufficient number of samples to allow significant correlations to be obtained. The advantage of FCP is the avoidance of panel training, as panelists only need to be able to use the scale and to be considered consumers of the product under evaluation.[35] Cristovam et al.[36] stated that while FCP can show large differences between the samples, it does not show the more discriminatory differences that would be revealed by conventional sensory profiling. In previous studies FCP has been applied to beef,[37,38] turkey,[39] ostrich,[40] chicken,[29] and pork.[41] Recently, Sieffermann[42] suggested combining free choice profiling with a comparative evaluation of the product set in a technique named Flash profile. Rason et al.[43] used the Flash profile method when evaluating sensory characteristics of traditional dry sausages.

A more structured approach to FCP has been developed incorporating the repertory grid method (RGM) as a prior step. This method is mainly suited to vocabulary development and can therefore solve the difficulties in generating sufficient and suitable descriptors, a problem which usually arises when working with consumers.[44] The RGM was applied to chicken in conjunction with FCP.[29]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

10.3 Panel Selection

Many researchers have discussed the selection of panelists for descriptive analysis, indicating the screening tests to be performed and also how the panelists can be monitored.[4,5,45–47] All descriptive analysis methods require a panel with some degree of training. In most cases panelists are also required to have a reasonable level of sensory acuity, with the exception of FCP. Previous papers have discussed the selection of sensory panelist and screening tests to be performed. Panelist selection is a critical aspect of descriptive analysis.[4,5] A prospective flavor panelist should be able to describe sensations and should be able to discriminate between taste and aroma sensations.[6] Panelists must be able to detect and describe the perceived sensory attributes of the product. The qualitative aspects of a product combine to define the product; they include all the appearance, aroma (odor), flavor, texture, or sound characteristics of the product that differentiate it from other products. Panelists must also learn to differentiate and rate quantitatively the intensity of the product and to define the level of each characteristic present in the sample. Two meat products might contain the same qualitative descriptors but their intensity may differ significantly between the two samples, thus resulting in different and quite distinctive sensory profiles of the product. The two samples below have the same qualitative descriptors but they differ considerably in the intensity of the characteristic (quantitative). The level or intensity of the characteristic is recorded on a 15-point scale (0 = none and 15 = extreme).

Attribute	287	131
Browned	4.5	3.1
Meaty	8.0	1.4
Rancid	1.1	8.7

The two samples of beef have the same flavor descriptors; however, they differ significantly in the intensity of each flavor note. Sample 287 has a distinct browned, meaty flavor, with a small underlying rancid note. Sample 131 also has a browned flavor note with a slight meaty flavor and a predominant rancid flavor.

A good descriptive analysis panel requires extensive training by an experienced panel leader. This sensory professional will be trained and experienced in the analytical method being applied. Once trained, a descriptive panel operates as an instrument, meaning that data must be replicated, as with any instrument.[5] This training begins once the panelist screening and selection stages are complete. The overall goal of the training is to familiarize the panelist with the test procedures, to improve their ability to recognize the sensory attributes, and also to improve the panelist's sensitivity to and memory for test attributes so that sensory judgment will be precise and consistent. Reaching agreement among assessors is one of the main objectives of training a descriptive panel.[48]

These basic guidelines should be followed as part of the sensory analysis of meat products: (1) As part of the training for a panel on meat products, panelists should be instructed on the general biology of muscle foods, that is, to understand what muscle fiber structure is and what connective tissue is, etc. (2) Panelists should also be instructed on how to chew the meat sample, how to swallow or regurgitate, and to rinse the palate between samples. This is important in texture evaluation as experimental treatment effects may be concealed or not clearly differentiated if biting and mastication are not uniform. (3) All samples must be prepared as uniformly as possible to ensure sample-to-sample variation is due to experimental treatments rather then during preparation. (4) Samples should be served as quickly as possible after cooking to avoid changes that may occur (e.g., development of off-flavors or drying of sample).

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

10.4 Descriptor Development

The general background to descriptive analysis aims at agreement by the panel on the use of a common list of descriptors. The selected descriptors should therefore account for and refer to the human perception of the sensory attributes of the product (with the exception of FCP). Inherent product variations, processing effects, and storage effects can be effectively compared from a sensory perception. Sensory terminology is very important in descriptive analysis, and perceptions are greatly influenced by the language. The final descriptive language should be accurately defined and should contain enough terms to include all attributes likely to be encountered; however, it should not be so large as to be unmanageable.[49] The sensory descriptors should be descriptive, with clear and precise meaning for consistent panel performance and for a platform from which results can be repeated and compared in the future.

Generally, a new panel will develop their own sensory language with the input from an experienced leader. An existing language may also be used; however, if it is developed in another country, difficulties in understanding the interpretation may arise. In this situation, definitions are essential for translation purposes as word-for-word translations of descriptors are known to be difficult to achieve or even confusing.[50] Panelists often prefer to link descriptors together to assist in the panel's interpretation of particular attributes (e.g., rancid/painty and burnt/caramel/browned). One of the main applications of a defined sensory language is to improve the understanding of a product's flavor and texture. Using definitions is an attempt to ensure that panelists refer to the same sensory concept[51] and may also reduce any ambivalence in meaning that may arise in the panel. However, many sensory attributes are not easily defined and often fail to provide a frame of reference for all panelists to describe the concept. The use of full definitions and references/standards maximizes clarity and minimizes confusion. Ishii and O'Mahony[52] recommend multiple references, as panelists identify better with certain references. For example, the flavor descriptor oxidized/rancid/free fatty acid is defined as the flavor associated with rancid fat or as the aromatics associated with short-chain fatty acids. Panelists may be unfamiliar with the words or concepts; hence, the definition does not necessarily provide a frame of reference. Many authors have therefore recommended the use of reference standards to achieve concept alignment in sensory panels.[6,7,53,54] For example, when a panelist is provided with butyric acid as a chemical reference or feta cheese as a food reference, a concept and common point of reference becomes readily grasped by all panelists. Descriptor references can be qualitative, quantitative, or both.[55] For lexicons, qualitative or intensity references are not generally provided for each attribute. Qualitative references allow panelists to associate the concept of the term and reduce the amount of time required to train the sensory panel[54] and also to calibrate the panel in the use of the intensity scale. Quantitative references are used as part of the training of panelists to allow the panel to concentrate on the identified language and are a mandatory part of most descriptive panel training.[6]

10.5 Meat Texture Descriptors

Descriptive texture analysis aims to allow the description of texture from first bite through to complete mastication and also accounts for temporal aspects of attributes. It occurs in several logical stages which may vary slightly between studies. The stages are evaluation of the surface properties, partial compression properties, first bite properties, mastication, and residual properties. The descriptors for muscle foods do not tend to vary from one species to another. Table 10.2 shows the descriptors used for a variety of muscle foods (pork, beef, restructured beef, frankfurters, chicken, and lamb). The first evaluation stage involves the surface properties of the meat product such as smoothness, surface

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 10.2 Texture Descriptors for Various for Cooked Meats

Character Note	*Pork*[56–58]	*Chicken*[56,59]	*Lamb*[60]	*Beef*[55]	*Restructured Beef*[61,62]	*Frankfurters*[63]
Surface properties	Smoothness	Oiliness/ wetness	Smoothness	Oiliness/wetness	None	Surface moisture
	Surface moisture	Roughness	Surface moisture	Roughness		Type of moisture
	Fat type		Fat type			Surface smoothness
	Greasy (%)					
	Greasy and oily (%)					
	Fat amount					
	Amount of particles					
Partial compression properties	Elasticity	Springiness	Elasticity	Springiness	Springiness	Elasticity
First bite properties	Springiness	Firmness/ hardness	Compressibility (cohesiveness)	Firmness/ hardness	Hardness	Hardness
	Hardness	Cohesiveness	Moisture release	Cohesiveness	Cohesiveness	Cohesiveness
	Compressibility	Juiciness/ moisture release	Amount of fat	Juiciness or moisture release	Moisture release	Uniformity
	Moisture release		Type of fat	Uniformity of bite	Uniformity	Moisture release

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

	Fat amount		Cohesiveness (disintegration)			Denseness
	Fat type					Coarseness
	Greasy (%)					Graininess
	Greasy and oily (%)					
	Cohesiveness					
Mastication properties	Cohesiveness of mass	Cohesiveness of mass	Chewiness	Cohesiveness of mass	Sample breakdown after two chews	Chewiness
	Hardness of mass	Uniformity of mass	Number of chews	Uniformity of mass	Juiciness	Moisture release
	Fibrousness (between teeth)	Juiciness	Stringiness (fibrousness)	Juiciness	Size of chewed pieces	Oiliness
	Chewiness	Fibrousness	Moisture release	Gristle	Gristle	Moisture absorption
	Number of chews	Saliva produced	Moisture absorption	Connective tissue	Cohesiveness of mass	Cohesiveness of mass
	Stringiness	Particle size and shape	Cohesiveness of mass		Uniformity of mass	Lumpy
	Moisture release	Chewiness	Fat type		Webbed connective tissue	Grainy
	Moisture absorption	Chew count	Fat amount		Number of chews	Skin
	Cohesiveness	Bolus size	Rate of breakdown		Overall gristle	Description of breakdown

(*continued*)

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 10.2 (continued) Texture Descriptors for Various for Cooked Meats

Character Note	*Pork*[56–58]	*Chicken*[56,59]	*Lamb*[60]	*Beef*[55]	*Restructured Beef*[61,62]	*Frankfurters*[63]
	Fat type	Bolus wetness	Uniformity		Overall webbed connective tissue	
	Greasy (%)		Density			
	Greasy and oily (%)		Connective tissue			
	Fat amount		Connective tissue amount			
	Rate of breakdown					
	Uniformity					
	Density					
	Connective tissue type					
	Webbed fibers (%)					
	Webbed fibers and gristle (%)					
	Connective tissue amount					
Residual properties	Oily/greasy film	Ease of swallowing		Tooth pack	Tooth pack	Ease of swallowing
	Ease of swallowing	Tooth pack		Number of particles	Mouth coating	Mouth coating

Downloaded From Vet-eBooks.com

	Mouth coating type	Residual particles		Oiliness/ greasiness		Oiliness
	Particles and grease (%)	Mouth coating				Particles
	Particles (%)	Oiliness/ greasiness				
	Particles and ibers (%)					
	Mouth coating amount					
	Loose particles					
	Particle type					
	Particle amount					
	Tooth packing					

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

moisture, fat type, and roughness. The amount of particles and the debris on the surface of the product can also be evaluated. The partial compression stage analyses the degree to which the meat sample returns to its original form, that is, the springiness, elasticity, or rubberiness of the product.

During the first bite stage, the texture properties which are analyzed are springiness, hardness/firmness, cohesiveness/disintegration, moisture release/juiciness. The terms denseness, coarseness, and graininess were used in a texture lexicon to describe frankfurters.[63] The amount of fat and type of fat (greasy % and greasy and oily %) were also evaluated in pork and lamb.[56,60]

During the mastication/chewdown stage, cohesiveness of mass, fibrousness/stringiness, chewiness/number of chews, description/rate of breakdown, uniformity of mass and density were important factors which were evaluated in the majority of meat products in Table 10.2. Other factors which were assessed included moisture release and absorption, bolus size and wetness, fat type and amount, connective tissue type, and gristle. Civille and Liska[63] also used the terms lumpy, grainy, and skin under mastication properties of frankfurters.

Residual characteristics (after swallowing) included the ease of swallowing, presence of mouth coating and type, tooth pack, oiliness or greasiness, particle type and amount, residual particles type, and amount.

Several studies have reported the use of a texture profile panel for measuring the effects of processing procedure on the texture of restructured meats.[62,64,65] In a study by Guerrero et al.[66] four texture descriptors were evaluated (hardness, pastiness, crumbliness, and adhesivity) using a nonstructured quantitative scale ranging from 0 (absence) to 10 (intense). To illustrate the maximum intensity for each of these descriptors in dry-cured ham, reference products were used. The texture descriptors' hardness, adhesiveness, crumbliness, pastiness, fibrousness, and fat melting were evaluated on dry-cured ham samples.[23] Examples of texture terms and their definition are shown in Table 10.3.

10.6 Meat Flavor Descriptors

Historically, flavor has been considered an important quality attribute of meat and comprises mainly of the two sensations taste and aroma or smell. Although both of these factors affect the overall acceptability of foods, the aroma or flavor volatiles are of utmost importance because they influence the judgment of the panelist, even before the food is consumed. In their raw state, muscle foods have little flavor of their own; however upon heat processing their specific meaty aroma develops.[67,68]

Scientists describe five basic tastes: bitter, salty, sour, sweet, and umami. The basic tastes of sweet, sour, salty, and bitter can be found at low to moderate intensities in the various muscle foods. Sweet and salty naturally have low intensities in fresh meat but can be more intense in cured meats. Taste compounds are nonvolatile or water-soluble compounds with taste or tactile properties, including inorganic salts and sodium salts of certain acids (salty), hypoxanthine, peptides and some amino acids (bitter), sugars and some amino acids (sweet), and acids (sour).[69] Umami is a Japanese word meaning "savory," "meaty," or "delicious flavor" and thus applies to the sensation of savoriness. It is represented by glutamates and 5′-nucleotides, which are especially common in meats and other protein-heavy foods. The action of umami receptors explains why foods treated with monosodium glutamate (MSG) often taste *fuller*. Several umami substances are used as flavor enhancers.[70]

The recent identification by Laugerette et al.[71] of CD36 (fatty acid transporter [FAT]) as a taste receptor for fatty acids provides insight into the molecular basis of our preference for fat. As we gain more information regarding the function of this receptor, we may be able to devise

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 10.3 Examples of Texture Terms Used in Sensory Texture Profiling of Meat Products

Term	*Definition*
Chewiness	Number of chews required to masticate the meat sample to a consistency suitable for swallowing
Cohesiveness of mass	Degree to which the bolus holds together after product mastication
Cohesiveness	The amount the sample deforms before it ruptures or comes apart when biting between the molars
Ease of swallowing	Degree to which bolus can be readily swallowed
Hardness	Force required to compress the sample with molars or incisors
Fibrousness	The amount of grinding of fibers required to chew through sample
Graininess	Amount of small particles present in sample
Gristle	Amount of rubbery particles present
Juiciness	Amount of juice released after 10 chews
Loose particles	The amount of particles left in and on the surface of the mouth after swallowing
Moisture absorption	Amount of saliva absorbed by product
Moisture release	The amount of wetness/moistness felt in the mouth after one bite or chew
Mouth coating	Type and amount of oily residue left on surface of mouth
Number of chews	The amount of chews required to prepare sample for swallowing
Smoothness	Absence of particles, small bumps/lumps or grains in the product
Springiness/ Elasticity	Degree to which a product returns to its original shape after partial compression (without failure) between the tongue and palate or teeth
Tooth pack	Amount of sample remaining in, around, and between teeth
Surface moisture	Degree to which sample feels wet/oily on the surface
Uniformity of bite	Evenness of force during mastication
Uniformity of mass	Degree to which sample is uniform
Webbed tissue	Amount of webbedlike connective tissue present

better strategies to address the addictive potential of dietary fat which could serve as a possible target for treatment of obesity. Hence, if there is a connection between CD36 and our preference for fat, this would allow fat to join the five previously identified tastes that govern the experience of food.[71]

Substances in raw meat of particular importance for flavor forming reactions include free amino acids, peptides, sugars, and also phospholipids and their fatty acids, while various vitamins

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and minerals change the rate and extent of these reactions.[72,73] The amounts and proportions of these compounds will determine the progress of these flavor forming reactions and therefore the ultimate flavor of the cooked meat. Amino acids, peptides, and carbohydrates constitute the basis of meat flavor precursors. It has been suggested that the basic meaty aroma of beef, pork, and lamb is the same and is derived from the water-soluble fraction of the muscle which is a reservoir of low-molecular weight compounds.[74,75]

Meat flavor develops during cooking by complex reactions between natural components present in the raw meat. The cooking of meat generates many hundreds of volatile compounds, but relatively few make a key contribution to the odor and flavor of cooked meat.[76] The role of lipids in meat flavor generation has been studied extensively. An example of the link between lipid composition and flavor is that of concentrate-fed versus grass-fed beef. It has been suggested that the flavor of the concentrate-fed beef is preferred with the flavor of the grass-fed beef described as having "milky," "grassy" flavor notes.[77] The reactions between amino compounds and reducing carbohydrates are another important route to formation of flavor compounds in cooked foods.[78] Whitfield[79] showed that temperatures above 110°C promote Maillard reactions in meat. The Maillard reaction occurs when the denatured proteins on the surface of the meat recombine with the sugars present. This combination creates the "meaty" flavor and changes the color of the meat. The water content in meat is high, and the formation of flavor compounds by the Maillard is, therefore, generally located in the areas of the meat where the heat source has dehydrated the meat.[80]

Apart from microbial spoilage, lipid oxidation is one of the major causes of quality deterioration in muscle foods and processed meats[81] resulting in rancidity, off-flavors and off-odors as well as color and texture deterioration.[82–85] The interaction of lipid oxidation products in the thermally-induced reaction between amino acids and sugars is very important for the development of desirable meaty flavors in cooked meats.[86,87] The relationship between rancidity and flavor is unclear. As rancid flavors develop there is a loss of desirable flavor notes.[88] A study was conducted by Campo et al.[88] to determine the relationship between human perceptions, as determined by a trained panel, to a chemical measurement of lipid oxidation. Oxidation provokes deterioration of beef flavor throughout display and it was this that could be closely related to thiobarbituric acid reactive substances (TBARS).[88] The study concluded that TBARS value of 2 could be the limiting point from where rancid flavor overpowers beef flavor, and therefore, was considered as the maximum level for the positive sensory perception of beef.

10.6.1 Mouthfeel Characteristics in Meat Products

There are two mouthfeel factors commonly found in all muscle foods, astringent and metallic.[89,90] Astringency is not a taste or odor sensation but it must be included in flavor evaluation because it is common to many foods. Metallic mouthfeel in meat products is attributed to high myoglobin and hemoglobin contents since these proteins release iron during cooking. Increased hemoglobin may also be caused by improper blood removal during processing. This off-flavor may be reduced by cooking beef to a lower degree of doneness. Ruiz Pérez-Cacho et al.[91] also included two trigeminal sensation descriptors, "irritant" (describes a product causing a sensation of heat/burning in the buccal cavity as produced by pepper) and "piquancy" (describes a product causing sharp sensations of nasal mucous membrane as produced by pepper) in a detailed lexicon for dry-cured sausages.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

10.6.2 Lipid Oxidation and Warmed-Over Flavor in Meat Products

The term warmed-over flavor was first introduced by Tims and Watts[92] to describe the development of off-flavors in cooked meats within the first 48 h of refrigeration. In meats this distinctive off-flavor can become readily apparent with in a few hours of thermal processing and is most evident in refrigerated cooked meat products when they are reheated. This rapid development was the most significant factor that differentiated WOF from the ordinary rancidity flavors that develop during long term storage. This is in contrast to the slowly developing rancidity that becomes evident only after long periods of storage.[93] Stale or off-flavor notes such as "ice box," "rancid," and "freezer burn" have been used to describe this occurrence. Meat products develop stale off-flavors which are undesirable to consumers and at the same time the desirable meaty flavors notes are lost. After cooking, lipid oxidation is often considered synonymous with WOF, characterized by the loss of fresh cooked meat aroma and a simultaneous increase in undesirable off-flavors commonly described as "warmed-over," "stale," "rancid," "wet cardboard," "painty," or "grassy."[88,94,95]

The high susceptibility of phospholipids to oxidation is attributed to the high concentration of polyunsaturated fatty acids. Phospholipids are generally accepted as the main substrate for the formation of oxidation products associated with WOF.[94,96,97] Meat flavor deterioration (MFD) is also currently used to describe this undesirable flavor.[98] However, autoxidation, which is a continuous free radical chain reaction,[93] is still hypothesized as the major reaction responsible for WOF of precooked roast beef. The normal resistance of meat to the development of rancidity depends on the balance between the presence of antioxidants in the animal tissues, the level of unsaturation and the concentration of fatty acids present.[99] Poultry meat is composed of relatively high levels of unsaturated fatty acids and low levels of natural tocopherols and thus poultry products are very susceptible to the development of off-flavors. In chicken, lack of α-tocopherol is the main reason for MFD and the formation of undesirable WOF products. However, cooked turkey meat, despite a higher content of unsaturated lipids, may not readily develop WOF because it contains endogenous α-tocopherol.[100] Researchers have shown that lipid oxidation in muscle foods takes place in the order, fish > poultry (turkey and chicken) > pork > beef > lamb.[81,101] This ordering is associated with the increasing levels of more susceptible fatty acids in each of the tissue phospholipids of these species and to the level of natural antioxidant present.[77]

Johnsen and Civille[15] developed a standardized lexicon of meat descriptors and reported that WOF was identifiable in meat from various species (beef, pork, turkey, and chicken) or various treatments (grilling, steaming, baking) within species, while samples varied in intensity. Sensory terminology to describe WOF has also been described by researchers in pork,[102–104] chicken,[105–107] lamb,[108] and beef.[94] The development of WOF descriptors and references by sensory analysis has much potential in the further elucidation of WOF and lipid oxidation in muscle foods. Several sensory descriptive vocabularies for WOF in meats of different species have been prepared. These WOF vocabularies can be used by panelists to describe perceived sensory characteristics in a sample set. The resultant profile is a perceptual map of the variations in the sample type that can be applied alone or in combination with chemical or instrumental data to help explain or elucidate underlying sensory and chemical relationships.

St Angelo et al.[108] used the following lexicon to describe WOF in lamb: meaty (the flavor associated with cooked muscle meat, such as beef), gamey/muttony (the flavor associated with muscle meat from wild game or older lambs), musty/herby (associated with wet soil/mulch and dried herbs such as rosemary or thyme), browned/caramel (associated with the outside of grilled or broiled lamb, seared but not burnt), grainy/cowy (associated with cow meat and/or meat

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

in which grain fed character was detectable), bloody/serum (associated with raw lean meat), livery (associated with organ meats such as liver), fatty (associated with cooked lamb fat), painty (similar to linseed oil and associated with rancid fat or oil), and cardboardy (similar to wet cardboard and associated with refrigerated cooked meat). The basic tastes of sweet, sour, bitter, and salty along with the aftertaste astringent were also used as descriptors. Byrne et al.[103,106] described sensory terms for WOF. In chicken sensory profiling with WOF and oven cooking temperature variation, WOF was described by increased "rancid" and "sulfur/rubber" sensory descriptors associated with a simultaneous decrease in chicken "meaty" flavor. Cooking temperature was described by increased "roasted," "toasted," and "bitter" sensory descriptors. A sweet, fresh pork, or chicken meatlike to linseed oillike, rancidlike flavor note, indicating a loss of freshly cooked "meatiness" as oxidation proceeds and WOF develops, was apparent in the three vocabularies.[103,104,106]

10.6.3 Boar/Sex Taint

Boar/sex taint is a well-known off-flavor in meat from pigs, mostly male pigs, that is, boars. Boar taint/sex taint is an unpleasant urinelike odor that is released during cooking from some pork and products made from the meat and fat of noncastrated male pigs; however, only a proportion of boars produce this odor and not all consumers are sensitive to it. It is primarily due to high levels of androstenone and/or skatole in pig carcasses. Font-I-Furnois[41] described the sensory characteristics of boar taint using a modified FCP technique and the odor and flavor descriptors "urine," "sweat," "chemical," and "rancid," and flavor descriptors "turpentine," "viscera," "pig/animal," "naphthalene," and "piquant." Other descriptive analysis studies on boar taint in pork have also used the descriptors "boar flavor," "pig," "manure/stable," "abnormal," "sweet," "naphthalene/mothballs."[109,110]

10.6.4 Flavor Lexicons

A flavor lexicon is a set of words to describe the flavor of a product. The lexicon is then applied using descriptive sensory techniques as described previously. A key characteristic of a good flavor lexicon is that it be discriminating and descriptive.[6] Characteristics of flavor lexicons have been discussed in the past by Lawless and Heymann[5] and Civille and Lawless.[111] A lexicon is a source list to describe a category of products (beef, pork, lamb) or finished products (meat patties, frankfurters). Table 10.4 shows the flavor languages used in the sensory analysis of meat flavor.

The flavor attributes mustiness (flavor that evokes the smell of a damp poorly ventilated cellar), sweetness, piquantness (pungent stimulating to the palate), bitterness, aged flavor (a pleasant incipient rancid flavor typical of dry-cured meat products aged for a long period), cured flavor (complex flavor developed during the curing and aging process and typical of dry-cured meat products) were evaluated using a flavor lexicon for dry-cured pork shoulders by Sárraga et al.[23] Fishy (cod liver oil or old fish flavor), saltiness, and metallic flavors were evaluated in dry-cured pork shoulders and also cured hams and cooked ham flavor (typical cooked ham flavor) in cooked hams only.[23]

A specific descriptive lexicon was developed by Flores et al.[112] to evaluate the flavor of Spanish dry-cured ham. The following aromatic descriptors "fat complex," "boar taint," "barnyard," "haylike/musty," "brown spice," "pickling spice," "smoky," "pork," "serum," "pungent," with basic taste descriptors "sour," "salty," "bitter" and feeling factors "astringent," "metallic," and "mountfilling" were evaluated. The flavor lexicon is used by researchers to study the flavor development during the

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 10.4 Flavor Languages Developed and Used for Sensory Analysis of Meat Flavor

Meat Product	*Descriptive Vocabularies*
Ground beef[113,114]	Odor: putrid, sweaty, rancid, animal, blood, fatty, oily, meaty, raw meat, fishy, painty, herbal, milky-oily, cooked beef fat, sour
	Flavor: milky-oily, cooked beef fat flavor, sour, fishy, liver, metallic, off-flavor
Beef[15,38,88,115,116]	Flavor: beefy, brothy/meaty, cooked beef fat, serum/bloody, browned, livery/organ meat, grainy/cowy, herbal, acidic, chemical, beef fat, browned, dry, salty, rich, fruity, toasty, burnt, nutty, milky, turpentine, juicy, oatmeal, oily, caramel, cooked vegetable, fresh, creamy, kerosene, bland, beef, broth, popcorn, tangy, musty, citrus, perfumelike, earthy
	Aromatics: cooked beer/brothy, grainy/cowy, serumy/bloody, cardboard, painty, fishy, livery, abnormal, rancid, greasy, metallic, acidic, vegetable, grassy, dairy
	Basic tastes: sour, bitter, salty, sweet
	Aftertastes: metallic, astringent
Pork[56,57,109,117–119]	Odor: roasted, caramel, burnt caramel, fresh cooked pork, piggy, buillon, linseed oil/paint, oxidized, egg/sulfur/rubber, fried meat, boiled meat, sour, sweet
	Tastes: sweet, sour, salt, bitter, MSG/umami
	Flavor: porky, piggy, sex taint/boar odor, fatty, bloody, heart/liver, browned, metallic, fresh cooked chicken, fresh cooked pork, rancid, cardboard, lactic acid/fresh sour, vegetable oil, briny, bread, fried meat, burnt caramel, boiled meat, umami
	Aftertastes: lactic/fresh sour, metallic, oxidized, fat, astringent
Poultry[104,120–122] (turkey and chicken)	Aromatic: chickeny, poultry flavor, meaty, brothy, liver/organy, browned, burned, cardboard/musty, warmed-over, rancid/painty
	Flavor: chickeny/poultry, meaty, brothy, browned, liver/organy, peanut/hazelnut
	Basic tastes: sweet, bitter
	Aftertastes: metallic
Lamb[108,123–125]	Odor: blood, lamb, meaty, sheep meat, boiled meat, bouillon, liver, poultry, animal, rancid, fat, oil, butter
	Flavor: gamey/muttony, bloody/serum, browned/caramel, livery/organ meat, lamb, meaty, sheepmeat, cabbage, roast, liver, poultry, animal, rancid, fat/fatty, oil, butter, rubber, milk, oxidized, fish, abnormal
Pork sausages[25]	Odor: fermenting, sausagey, vinegary, musty, sour, winey, rancid, sweet, yeasty

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 10.4 (continued) Flavor Languages Developed and Used for Sensory Analysis of Meat Flavor

Meat Product	*Descriptive Vocabularies*
Pork patties[126]	Odor: boiled meat, linseed oil, rancid, sweet, sour
	Flavor: boiled meat, linseed oil, rancid, bouillon
	Basic tastes: sweet, sour, bitter, salt
Ham[23]	Odor: metallic, cooked ham, fishy
	Flavor: metallic, cooked ham, fishy, salty
Dry-cured pork[23]	Odor: metallic, cooked ham, fishy
	Flavor: mustiness, sweetness, piguantness, bitterness, aged flavor, cured flavor, fishy, salty, metallic
Bacon[57]	Flavor: smoked, sweet, salt, cured fat, cured lean, cured meaty/fatty
	Brown sugar
	Molasses, burnt
	Aftertastes: sweet, salty, smoked, meaty

curing process. Previous sensory attributes to describe dry-cured ham flavor were not well defined using terms such as dry-cured flavor, aged taste, aroma typical of dry-ham that are very subjective and will differ depending on the origin of the dry-cured ham.

A lexicon for describing the sensory attributes of a Spanish dry-cured sausage (salchichón) was developed.[91] A highly trained, descriptive sensory panel generated, defined, selected, and referenced the main sensory characteristic of commercial salchichón elaborated from meat of white pig. The language was not only descriptive but also discriminative. Panelists initially produced a vocabulary of 108 terms that were later modified to 15 attributes: four for appearance (luminance, presence of crust, fat/lean connection, and exudate); four for odor (black pepper, lactic acid, mold, and other spices); two for texture (hardness and initial juiciness); and five for flavor (black pepper aroma, mold aroma, other spices aroma, acid taste, and salty taste).

10.7 Odor in Meat Products

The sensation of odor is produced by volatile substances which stimulate receptors in the nasal epithelium. Odor plays a major part in defining the characteristic flavor of a food and is a crucial sensory attribute that may determine whether consumers will accept a food product. While odor is generally caused by low-molecular-weight volatile compounds, taste substances are usually much larger and water soluble. More than 1000 volatile compounds have been identified in cooked meat aroma.[78] However, it is believed that only a small number of compounds actually play an important role in the overall aroma of cooked meat. A further class of nonvolatile components, known as flavor enhancers, do not necessarily possess a taste or aroma themselves but enhance the flavor of other compounds.[73] In cooked meats many of the volatile compounds

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

are formed by chemical reactions caused by heating and these reactions are the main source of odor compounds in cooked meat.[72]

Roller et al.[25] used QDA to obtain nine odor attributes (fermenting, musty, rancid, sausagey, sour, sweet, vinegary, winey, yeasty) of pork sausages. The panelist were trained to recognize standardized odor attributes and to assess their intensity on a 0–4 scale (nondetectable—very strong) and similarly the overall acceptability in terms of odor and appearance on a 1–7 scale (extremely acceptable—extremely unacceptable). Campo et al.[127] investigated the contribution of muscle components in the development of cooked meat odor in an aqueous model system using trained sensory panelists. Following training and assessment, the following odor descriptors completed the odor profile of cooking mixtures of fatty acids, sugar and amino acids, corned beef, meaty, fatty, cooking oil, oily, wax, fish oil, linseed oil, grassy, creosote/tarmac, rubbery, gassy/eggy, sharp, pungent, and sweet.

Instruments that separate compounds and indicate their concentration include gas chromatography (GC), high pressure liquid chromatography, and sensing devices referred to as "electronic noses."[128] Investigations of odor/aroma of meat products can be aided with gas chromatic separation and olfactory analysis in which a human subject qualitatively evaluates the aromas of individual compounds separated by GC. The analysis of characteristic food odors has been commonly carried out by human assessment and headspace/direct gas chromatography-mass spectrometry (GC/MS).[129]

10.8 Conclusions

Descriptive analysis is the most comprehensive, flexible, and useful sensory method, providing an in-depth description on all of a product's sensory properties. In meat research, sensory descriptors are an essential tool for accurately documenting the description of cooked meat products. Sensory scientists should adhere to those recommended practices required to guarantee sensory panel performance: thorough screening and selection of panelists, extensive training that includes descriptor development, definitive references, continuous monitoring of sensory panel, and experimental controls for sample preparation and evaluation.

References

1. Meilgaard, M.C., Civille, G.V. and Carr, B.T. *Sensory Evaluation Techniques*, 2nd ed., CRC Press, Boca Raton, FL, 1991.
2. Cross, H.R., Berholdt, M.F., Dikeman, M.E., Greene, B.P., Moody, W.G., Stagge, R. and West, R.L. Recommended guidelines for cookery and sensory evaluation of meat. *Ad-Hoc Committee on 'Guidelines for Cookery and Sensory Evaluation of Meat'*, American Meat Science Association (AMSA), Auburn, AL, 1978.
3. Keane, P. The flavor profile. In: *Descriptive Analysis Testing for Sensory Evaluation*, Hootman, R.C. Ed., American Society for Testing Materials (ASTM) Manual Series 13, Philadelphia, PA, 1992, pp. 5–14.
4. Meilgaard, M.C., Civille, G.V. and Carr, B.T. *Sensory Evaluation Techniques*, 3rd ed., CRC Press, Boca Raton, FL, 1999.
5. Lawless, H.T. and Heymann, H. Qualitative consumer research methods. In: *Sensory Evaluation of Food*, Lawless, H.T. and Heymann, H.Eds, Chapman & Hall, New York, 1998, pp. 519–547.
6. Drake, M.A. and Civille, G.V. Flavour lexicons. *Comprehensive Rev. Food Sci Food Safety*, 2, 33–40, 2003.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

7. Murray, J.M. and Delahunty, C.M. Selection of standards to reference in a cheddar cheese flavour language. *J. Sensory Stud.*, 15, 179–199, 2000.
8. Brant, M.A., Skinner, E.Z. and Coleman, J.A. Texture profile method. *J. Food Sci.*, 28, 404–409, 1963.
9. Szczesniak, A.S. Classification of textural characteristics. *J. Food Sci.*, 28, 385–389, 1963.
10. Szczesniak, A.S., Brandt, M.A. and Friedman, H.H. Development of standard rating scales for mechanical parameters of texture correlation between the objective and the sensory methods of texture evaluation. *J. Food Sci.*, 28, 397–403, 1963.
11. Civille, G.V. and Szczesniak, A.S. Guidelines to training a texture profile panel. *J. Texture Stud.*, 4, 204–223, 1973.
12. Jeremiah, L.E., Gibson, L.L. and Burwash, K.L. Descriptive sensory analysis: The profiling approach. *Research Branch Technical Bulletin*, 1997-2E, 1, 1997.
13. Muñoz, A.M. and Civille, G.V. Spectrum descriptive analysis. In: *ASTM Manual Series MLN 13 Manual on Descriptive Analysis Testing for Sensory Evaluation,* Hootman, R.C. Ed., American Society of Testing and Materials, West Conshohocken, PA, 1992, pp. 22–34.
14. Murray, J.M., Delahunty, C.M. and Baxter, I.A. Descriptive sensory analysis: Past, present and future. *Food Res. Int.*, 34, 461–471, 2001.
15. Johnsen, P.J. and Civille, G.V. A standard lexicon of meat WOF descriptors. *J. Sensory Stud.*, 1, 99–104, 1986.
16. Rababah, T., Hettiarachchy, N.S., Eswaranandam, S., Meullenet, J.F. and Davis, B. Sensory evaluation of irradiated and nonirradiated poultry breast meat infused with plant extracts. *J. Food Sci.*, 70, 228–235, 2005.
17. Cavitt, L.C., Youm, G.W., Meullenet, J.F., Owens, C.M. and Xiong, R. Prediction of poultry meat tenderness using razor blade shear, allo-kramer shear and sarcomere length. *J. Food Sci.*, 69, 11–15, 2004.
18. Stone, H., Sidel, J., Oliver, S., Woolsey, A. and Singleton, R.C. Sensory evaluation by quantitative descriptive analysis. *Food Technol.*, 28, 24–34, 1974.
19. Stone, H. and Sidel, J. Quantitative descriptive analysis: Developments, applications and the future. *Food Technol.*, 52, 48–52, 1998.
20. Stone, H. and Sidel, J. Descriptive analysis. In: *Encyclopedia of Food Science*, Stone, H. and Sidel, J., Eds, 2nd ed., Academic Press, London, 2003, pp. 5152–5161.
21. Krishnamurthy, R., Srivastava, A.K., Paton, J.E., Bell, G.A. and Levy, D.C. Prediction of consumer liking from trained sensory panel information: Evaluation of neural networks. *Food Qual. Pref.*, 18, 275–285, 2005.
22. Insausti, K., Beriain, M.J., Gorraiz, C. and Purroy, A. Volatile compounds of raw beef from 5 local Spanish cattle breeds stored under modified atmosphere. *J. Food Sci.*, 67, 1580, 2002.
23. Sárraga, C., Guàrdia, M.D., Díaz, I., Guerrero, L., García Regueiro, J.A. and Arnau, J. Nutritional and sensory quality of porcine raw meat, cooked ham and dry cured shoulder as affected by dietary enrichment with docosahexaenoic acid (DHA) and α-tocopheryl acetate. *Meat Sci.*, 76, 377–384, 2007.
24. Aleson-Carbonell, L., Fernández-López, J., Sayas-Barbeá, E., Sendrá, E. and Pérez-Alvarez, J.A. Utilization of lemon albedo in dry-cured sausages. *J. Food Sci.*, 68, 1826–1830, 2003.
25. Roller, S., Sagoo, S., Board, R., O'Mahony, T., Caplice, E., Fitzgerald, G., Fogden, M., Owen, M. and Fletcher, H. Novel combinations of chitosan, carocin and sulphite for the preservation of chilled pork sausage. *Meat Sci.*, 62, 165–177, 2002.
26. Stampanoni, C.R. Quantitative flavour profiling. *Int. Food Marketing Technol.*, 7, 4–8, 1993.
27. Stampanoni, C.R. The use of standardised flavour languages and quantitative flavour profiling techniques for flavoured dairy products. *J. Sensory Stud.*, 9, 383–400, 1994.
28. Stampanoni, C.R. Quantitative flavour profiling: An effective tool in flavour perception. *Food Marketing Technol.*, 2, 4–8, 1993.
29. Jahan, K., Paterson, A. and Piggott, J.R. Sensory quality in retailed organic, free range and corn-fed chicken breast. *Food Res. Int.*, 38, 495–503, 2005.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

30. Veberg, A., Olsen, E., Vogt, G., Mielnik, M., Nilsen, A.N. and Wold, J.P. Front face fluorescence spectroscopy—A rapid method to detect early lipid oxidation in freeze stored minced turkey meat. *J. Food Sci*., 71, 364–370, 2006.
31. Williams, A.A. and Arnold, G.M. The use of free-choice profiling for the evaluation of commercial ports. *J. Sci. Food Agric*., 35, 558–568, 1984.
32. Oreskovich, D.C., Klein, B.P. and Sutherland, J.W. Procrustes analysis and its application to free choice and other sensory profiling. In: *Sensory Science Theory and Application in Foods*, Lawless, H.T. and Klein, B.P. Eds., Marcel Dekker, New York, 1991, 353.
33. Gower, J.C. Generalised procrustes analysis. *Psychometrika*, 40, 33–50, 1975.
34. Jones, P.N., MacFie, H.J.H. and Beilken, S.L. Use of preference mapping to relate consumer preference to the sensory properties of a processed meat product (tinned cat food). *J. Sci. Food Agric*., 47, 113, 1989.
35. Piggott, J.R., Sheen, M.R. and Guy, C. Bridging the gap between laboratory flavour research and the consumer. In: *Charalambous, Flavour and Off-flavours, Proc. of the 6th International Flavour Conference*, Elsevier Science, Amsterdam, 1989, pp. 543–552.
36. Cristovam, E., Paterson, A. and Piggott, J.R. Differentiation of port wines by appearance using sensory panel: comparing free-choice profiling and conventional profiling. *Eur. Food Res. Technol*., 211, 65–71, 2000.
37. Beilken, S.L., Eadie, L.M., Griffiths, I., Jones, P.N. and Harris, P.V. Assessment of sensory characteristics of meat patties. *J. Food Sci.* 56, 1470–1475, 1991.
38. Bruce, H.L., Beilken, S.L. and Leppard, P. Variation in flavor and textural descriptions of cooked steaks from bovine *M. longissimus thoracis et lumborum* from different production and aging regimes. *J. Food Sci*. 70, 309–316, 2005.
39. Lynch, J.A., Macfie, H.J.H. and Mead, G.C. Effect of irradiation and packaging type on sensory quality of chilled-stored turkey breast fillets. *Int. J. Food Sci Technol*., 26, 653–668, 1991.
40. Soriano, A., García Ruiz, A., Gómez, E., Pardo, R., Galán, F.A. and González Viñas, M.A. Lipolysis, proteolysis, physicochemical and sensory characteristics of different types of Spanish ostrich salchichon. *Meat Sci*., 75, 661–668, 2007.
41. Font-I-Furnois, M., Guerrero, L., Serra, X., Ruis, M.A. and Oliver, M.A. Sensory characterization of boar taint in entire male pigs. *J. Sensory Stud*., 15, 393–409, 2000.
42. Sieffermann, J.M. Flash profiling. A new method of sensory descriptive analysis. In: *AIFST 35th Convention*, Sidney, Australia, 2002.
43. Rason, J., Léger, L., Dufour, E. and Lebecque, A. Relations between the know-how of small scale facilities and the sensory diversity of traditional dry sausages from the Massif Central in France. *Euro. Food Res. Technol*., 222, 580–589, 2006.
44. González-Thomás, L. and Costell, E. Sensory evaluation of vanilla-dairy desserts by repertory grid method and free choice profile. *J. Sensory Stud*., 21, 20–33, 2006.
45. Piggott, J.R. and Hunter, E.A. Review: Evaluation of assessor performance in sensory analysis. *Ital. J. Food Sci*., 4, 289–309, 1999.
46. Hootman, R.C. Manual on descriptive analysis testing for sensory evaluation. *ASTM Manual Series: MNL 13*, American Society of Testing and Materials, Philadelphia, PA, 1992, pp. 5–51.
47. Stone, H. and Sidel, J. *Sensory Evaluation Practices,* 2nd ed., Academic Press, London, Orlando, FL, 1993.
48. O'Mahony, M., Rothman, L., Ellison, T., Shaw, D. and Buteau, L. Taste descriptive analysis: Concept formulation, alignment and appropriateness. *J. Sensory Stud.*, 5, 71–103, 1990.
49. Piggott, J.R. and Canaway, P.R. Finding the word for it: methods and uses of descriptive sensory analysis. In: *Flavour '81*, Schreier, P., Ed., de Gruyter, Berlin, Germany, 1981, pp. 202–243.
50. Drake, M.A. Sensory textural/rheological properties a polygot list. *J. Textural Stud.*, 20, 1–27, 1989.
51. Giboreau, A., Dacremont, C., Egoroff, C., Guerrand, S., Urdapilleta, I., Candel, D. and Dubois, D. Defining sensory descriptors: Towards writing guidelines based on terminology. *J. Food Qual. Pref.*, 18, 265–274, 2007.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

52. Ishii, R. and O'Mahony, M. Use of multiple standards to define sensory characteristics for descriptive analysis: Aspects of concept formulation. *J. Food Sci*., 56, 838–842, 1991.
53. Rainey, B.A. Importance of reference standards in training panellist. *J. Sensory Stud*., 1, 149–154, 1986.
54. Muñoz, A.M. Consumer perceptions of meat. Understanding these results through descriptive analysis. *Meat Sci*., 49, 287–295, 1998.
55. Muñoz, A.M. and Civille, G.V. Universal, product, and attribute specific scaling and the development of common lexicons in descriptive analysis. *J. Sensory Stud*., 13, 57–76, 1998.
56. Jeremiah, L.E., Murray, A.C. and Gibson, L.L. The effects of differences in inherent muscle quality and frozen storage on the flavour and texture profiles of pork loin roasts. *Meat Sci*., 27, 305–327, 1990.
57. Averette Gatlin, L., See, M.T., Larick, D.K. and Odle, J. Descriptive flavour analysis of bacon and pork loin from lean-genotype gilts fed conjugated linoleic acid and supplemental fat. *J. Anim. Sci*., 84, 3381–3386, 2006.
58. Baublis, R.T., Meullenet, J.F., Sawyer, J.T., Mehaffey, J.M. and Saha, A. Pump rate and cooked temperature effects on pork loin instrumental, sensory descriptive and consumer rated characteristics. *Meat Sci*., 72, 741–750, 2005.
59. Lyon, B.G. and Lyon, G.E. Texture profile of broiler pectoralis major as influenced by post-mortem deboning time and heat method. *Poultry Sci*., 69, 329–340, 1990.
60. Jeremiah, L.E. A comparison of flavour and texture profiles for lamb leg roasts from three different geographical sources. *Can. Inst. Food Sci. Technol*., 21, 471–476, 1988.
61. Berry, B.W., Smith, J.J. and Secrist, J.L. Effects of flake size on textural and cooking properties of restructured beef and pork steaks. *J. Food Sci*., 52, 558–563, 1987.
62. Berry, B.W. and Civille, G.V. Development of a texture profile panel for evaluating restructured beef steaks varying in meat particle size. *J. Sensory Stud*., 1, 15–26, 1986.
63. Civille, G.V. and Liska, I.H. Modifications and applications to foods of the General Foods sensory texture profile technique. *J. Texture Stud*., 6, 19–31, 1975.
64. Cohen, S.H., Segars, R.A., Cardello, A., Smith, J. and Robbins, F.M. Instrumental and sensory analysis of the action of catheptic enzymes on flaked and formed beef. *Food Microstruc*., 1, 99–105, 1982.
65. Cardello, A.V., Segars, R.A., Secrist, J., Smith, J., Cohen, S.H. and Rosenkrans, R. Sensory and instrumental texture properties of flaked and formed beef. *Food Microstruc.* 2, 119–133, 1983.
66. Guerrero, L., Gou, P. and Arnau, J. The influence of meat pH on mechanical and sensory textural properties of dry-cured ham. *Meat Sci*., 52, 267–273, 1999.
67. Shahidi, F. Flavour of cooked meats. In: *Flavour Chemistry: Trends and Developments*. Teranishi, R., Buttery, R.G. and Shahidi, F. Eds., ACS Symposium Series 388. American Chemical Society, Washington, DC, 1989, pp. 180–201.
68. Farmer, L.J. Meat flavor. In: *The Chemistry of Muscle-Based Foods*. Johnston, D.E., Knight, M.K. and Ledward, D.A. Eds., Royal Society of Chemistry, London, 1992, 169–182.
69. Moody, W.G. Beef flavour—A review. *Food Technol.* 37, pp. 227–232, 239–248, 1983.
70. Kawanura, Y. and Kare, M.R. *Umami: A Basic Taste*, Marcel Dekker, New York, 1987.
71. Laugerette, F., Passilly-Degrace, P., Patris, B., Niot, I., Febbraio, I., Montmayeur, J.P. and Besnard, P. CD36 involvement in orosensory detection of dietary lipids, spontaneous fat preference, and digestive secretions. *Clin. Invest.*, 115, 3177–3184, 2005.
72. Mottram, D.S. Meat. In: *Volatile Components in Foods and Beverages*, Maarse, H. Ed., Marcel Dekker, New York, 1991, pp. 107–177.
73. Farmer, L.J. The role of nutrients in meat flavour formation. *Proc. Nutr. Soc.*, 53, 327–333, 1994.
74. Hornstein, I. and Crowe, P.F. Meat flavour: Lamb. *J. Agric. Food. Chem*., 11, 147–149, 1960.
75. Hornstein, I. and Crowe, P.F. Flavour studies on beef and pork. *J. Agric. Food. Chem.*, 8, 494–498, 1963.
76. Farmer, L.J. Poultry meat Flavour. In: *Poultry Meat Science*, Richardson, R.I., Mead, G.C. Eds., CABI Publishing, Wallingford, CT, 1999, pp. 127–158.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

77. Melton, S.L. Effect of forage feeding on beef flavor. *Food Technol.*, 37, 239, 1983.
78. Mottram, D. Flavour formation in meat and meat products: A review. *Food Chem.*, 62, 415–424, 1998.
79. Whitfield, B. Volatiles from interactions of Maillard reactions and lipids. *Crit. Rev. Food Sci. Nutr.*, 31, 58, 1992.
80. van den Ouweland, G.A.M., Peer, H.G.F. and Tjan, S.B. Occurrence of Amadori and Heyns rearrangements products in processed foods and their role in flavour formation. In: *Flavour in Food and Beverages*, Charalambous, G. and Inglett, G.E. Eds., Academic Press, New York, 1978, pp. 131–143.
81. Rhee, K.S., Anderson, L.M. and Sams, A.R. Lipid oxidation potential of beef, chicken and pork. *J. Food Sci.*, 61, 8, 1996.
82. Kanner, J., Harel, S. and Granit, R. Oxidative processes in meat and meat products: quality implications. In: *Proc. 38th International Congress of Meat Sci Technol.*, Clemont-Ferrand, France, 1992, 111.
83. Gray, J.I., Goma, E.A. and Buckley, D.J. Oxidative quality and shelf life of meats. *Meat Sci.*, 43, 111–123, 1996.
84. Buckley, D.J., Morrissey, P.A. and Gray, J.I. Influence of dietary vitamin E on the oxidative stability and quality of pigmeat. *J. Anim. Sci.*, 1, 3122–3130, 1995.
85. Sárraga, C. and Garcia Regueiro, J.A. Membrane lipid oxidation and proteolytic activity in thigh muscles from boilers fed different diets. *Meat Sci.*, 52, 213–219, 1999.
86. Mottram, D.S. and Edwards, R.A. The role of triglycerides and phospholipids in the aroma of cooked beef. *J. Sci. Food Agric.*, 34, 517–522, 1983.
87. Whitfield, F.B., Mottram, D.S., Brock, S., Puckey, D.J. and Salter, L.J. Effect of phospholipid on the formation of volatile heterocyclic compounds in heated aqueous solutions of amino acids and ribose. *J. Sci. Food Agric.*, 42, 261–272, 1987.
88. Campo, M.M., Nute, G.R., Hughes, S.I., Enser, M., Wood, J.D. and Richardson, R.I. Flavour perception of oxidation in beef. *Meat Sci.*, 72, 303–311, 2006.
89. Love, J. Sensory analysis of warmed-over flavour in meat. *Food Technol.*, 42, 140–143, 1988.
90. Johnsen, P.J., Civille, G.V. and Vercellotti, J.R. A lexicon of pond-raised catfish descriptors. *J. Sensory Stud.*, 2, 85–91, 1987.
91. Ruiz Pérez-Cacho, M.P., Galán-Soldevilla, H., Léon Crespo, F. and Molina Recio, G. Determination of the sensory attributes of a Spanish dry-cured sausage. *Meat Sci.*, 71, 620–633, 2005.
92. Tims, M.J. and Watts, B.M. Protection of cooked meats with phosphates. *Food Technol.*, 12, 140, 1958.
93. Pearson, A.M., Gray, J.I., Wolzak, A.M. and Horenstein, N.A. Safety implications of oxidized lipids in muscle foods. *Food Technol.*, 37, 121–129, 1983.
94. St Angelo, A.J., Vercellotti, J.R., Legendre, M.G., Vinnett, C.H., Kuan, J.W., James, C.J.R. and Dupuy, H.P. Chemical and instrumental analyses of warmed-over flavour in beef. *J. Food Sci.*, 52, 5, 1163–1168, 1987.
95. St Angelo, A.J., Vercellotti, J.R., Dupuy, H.P. and Spanier, A.M. Assessment of beef flavour quality: A multidisciplinary approach. *Food Technol.*, 42, 133, 1988.
96. Pearson, A.M., Love, J.D. and Shortland, F.B. Warmed-over flavor in meat, poultry and fish. *Adv. Food Res.*, 23, 1, 1977.
97. Asghar, A., Gray, J.I., Buckley, D.J., Pearson, A.M. and Booren, A.M. Perspectives on warmed-over flavour. *Food Technol.*, 6, 102–108, 1988.
98. Spanier, A.M., Edwards, J.V. and Dupuy, H.P. The warmed-over flavour process in beef: A study of meat protein and peptides. *Food Technol.*, 42, 110–118, 1988.
99. Enser, M. What is lipid oxidation? *Food Sci. Technol. Today.*, 1, 151–153, 1987.
100. Shahidi, F. Lipid derived flavours in meat products. In: *Meat Processing: Improving Quality.* Kerry, J. and Ledward, D. Eds., CRC Press, Boca Raton, Florida, 2002, pp. 105–117.
101. Tichivangana, J.Z. and Morrissey, P.A. The influence of pH on the lipid oxidation of cooked meats from several species. *Irish J. Food Sci. Technol.*, 9, 99–106, 1985.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

102. Poste, L.M., Willemot, C., Butler, G. and Patterson, C. Sensory aroma scores and TBA values as indices of warmed-over flavor in pork. *J. Food Sci.* 51, 886–888, 1986.
103. Byrne, D.V., O'Sullivan, M.G., Dijksterhuis, G.B., Breide, W.P.L. and Martens, M. Sensory panel consistency during development of a vocabulary for warmed-over flavour. *Food Qual. Pref.*, 12, 171–187, 2001.
104. Byrne, D.V., Bak, L.S., Bredie, W.L.B., Bertelsen, G. and Martens, M. Development of a sensory vocabulary for warmed-over flavour: Part 1. Porcine meat. *J. Sensory Stud.*, 14, 47–55, 1999.
105. Lyon, B.G. Development of chicken flavour descriptive attribute terms aided by multivariate statistical procedures. *J. Sensory Stud.*, 2, 55–67, 1987.
106. Byrne, D.V., Bredie, W.L.B. and Martens, M. Development of a sensory vocabulary for warmed-over flavour II: In chicken meat. *J. Sensory Stud.*, 14, 47–65, 1999.
107. Byrne, D.V., Bredie, W.L.P., Mottram, D.S. and Martens, M. Sensory and chemical investigations on the effects of oven cooking on warmed-over favour development in chicken meat. *Meat Sci.*, 61, 127–139, 2002.
108. St Angelo, A.J., Koomaraie, M., Crippen, K.L. and Crouse, J. Acceleration of tenderization/inhibition of warmed-over flavour by calcium chloride-antioxidant infusion into lamb carcasses. *J. Food Sci.*, 56, 359–362, 1991.
109. Vestergaard, J.S., Haugen, J.E. and Byrne, D.V. Application of an electronic nose for measurements of boar taint in entire male pigs. *Meat Sci.*, 74, 564–577, 2006.
110. Dijksterhuis, G.B., Engel, B., Walstra, P., Font i Furnols, M., Agerhem, H., Fischer, K., Oliver, M.A., Claudi-Magnussen, C., Siret, F., Béague, M.P., Homer, D.B. and Bonneau, M. An international study on the importance of androstenone and skatole for boar taint: II. Sensory evaluation by trained panels in seven European countries. *Meat Sci.*, 54, 661–269, 2000.
111. Civille, G.V. and Lawless, H.T. The importance of language in describing perception. *J. Sensory Stud.*, 1, 203–215, 1986.
112. Flores, M., Ingram, D.A., Bett, K.L., Toldra, F. and Spanier, A.M. Sensory characteristics of Spanish "Serrano" dry-cured ham. *J. Sensory Stud.*, 12, 169–179, 1997.
113. Brewer, M.S. and Vega, J.D. Detectable odor thresholds of selected lipid oxidation compounds in a meat model system. *J. Food Sci.,* 60, 592–595, 1995.
114. Melton, S.L., Black, J.M., Davis, G.W. and Backus, W.R. Flavor and selected chemical components of ground beef from steers backgrounded on pasture and fed corn up to 140 days. *J. Food Sci.*, 47, 699–704, 1982.
115. Papadopoulos, L.S., Miller, R.K., Acuff, G.R., Vanderzant, C. and Cross, H.R. Effect of sodium lactate on microbial and chemical composition of cooked beef during storage. *J. Food Sci.*, 56, 341–347, 1991.
116. Berry, B.W., Maga, J.A., Calkins, C.R., Wells, L.H., Carpenter, Z.L. and Cross, H.R. Flavour profile analyses of cooked beef loin steaks. *J. Food Sci.*, 45, 5, 1113–1115, 1980.
117. Byrne, D.V., O'Sullivan, M.G., Dijksterhuis, G.B., Breide, W.P.L. and Martens, M. Descriptive sensory profiling and physical/chemical analyses of warmed-over flavour in pork patties from carriers and non-carriers of the RN– allele. *Meat Sci.*, 63, 211–224, 2003.
118. Kluber, E.F. III, Minton, J.E., Stevenson, J.S., Hunt, M.C., Davis, D.L., Hoagland, T.A. and Nelssen, J.L. Groeth, carcass traits, boar odor, and testicular and endocrine functions of male pigs fed progestogen, altrenogest. *J. Anim. Sci.*, 66, 470–478, 1988.
119. Meinert, L., Andersen, L.T., Bredie, W.P.L., Bjergegaard, C. and Aaslyng, M.D. Chemical and sensory characterisation of pan-fried pork flavour: Interactions between raw meat quality, ageing and frying temperature. *Meat Sci.*, 75, 229–242, 2007.
120. Ruiz, J.A., Guerreo, L., Arnau, J., Guardia, M.D. and Esteve-Garcia, E. Descriptive analysis of meat from broilers fed diets containing vitamin E or β-carotene as antioxidants and different supplemental fats. *Poultry Sci.*, 80, 976–982, 2001.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

121. Chambers, E. IV, Bowers, J.R. and Smith, E.A. Flavor of cooked, ground turkey patties with added sodium tripolyphosphate as perceived by sensory panels with differing phosphate sensitivity. *J. Food Sci*., 57, 521–523, 1992.
122. Cipra, J.S. and Bowers, J.A. Flavour of microwaved and conventionally heated returkey. *Poultry Sci*., 50, 703–706, 1971.
123. Carlucci, A., Napolitano, F., Girolami, G. and Montelone, E. Methodological approach to evaluate the effects of age at slaughter and storage temperature and time on sensory profile of lamb. *Meat Sci*., 52, 391–395, 1999.
124. Rousset-Akrim, S., Young, O.A. and Berdagué, J.L. Diet and growth effects in panel assessment of sheepmeat odour and flavour. *Meat Sci*., 45(2) 169–181, 1997.
125. Gasperi, F., Biasioli, F., Gallerani, G., Fasoli, S. and Piasentier, E. Training of a sensory panel for quantitative descriptive analysis of meat. *Ital. J. Food Sci*., 3, 259–267, 2005.
126. Nissen, L.R., Byrne, D.V., Bertelsen, G. and Skibsted, L.H. The antioxidative activity of plant extracts in cooked pork patties as evaluated by descriptive sensory profiling and chemical analysis. *Meat Sci*., 68, 485–493, 2004.
127. Campo, M.M., Nute, G.R., Wood, J.D., Elmore, S.J., Motramm, D.S. and Enser, M. Modelling the effect of fatty acids in odour development of cooked meats in vitro: Part I—sensory perception. *Meat Sci*., 63, 367–375, 2003.
128. O'Suillivan, M.G., Byrne, D.V., Jensen, M.T., Andersen, H.J. and Vestergaard, J. A comparison of warmed-over flavour in pork by sensory analysis, GC/MS and the electronic nose. *Meat Sci*., 65, 1125–1138, 2003.
129. Grigioni, G.M., Margaria, C.A., Pensel, N.A., Sánchez, G. and Vaudagna, S.R. Warmed-over flavour in low temperature-long time processed meat by an 'electronic nose'. *Meat Sci*., 56, 221–228, 2000.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 11

Sensory Descriptors for Dry-Cured Meat Products

Mónica Flores

Contents

11.1 Introduction 173
11.2 Dry-Fermented Sausages 176
11.2.1 Sensory Methods Applied to Dry-Fermented Sausages 176
11.2.1.1 Flavor Descriptors 176
11.2.1.2 Sensations and Texture Descriptors 183
11.2.1.3 Appearance Descriptors 183
11.3 Dry-Cured Ham 184
11.3.1 Sensory Methods Applied to Dry-Cured Hams 184
11.3.1.1 Flavor Descriptors 184
11.3.1.2 Sensations and Texture Descriptors 191
11.3.1.3 Appearance Descriptors 191
References 192

11.1 Introduction

The wide variety of processed meat products depends on the ingredients and additives used in their formulation as well as the type of processing [1]. The sensory characteristics developed in cured meat products treated with salt and sodium nitrite are completely different depending on the process applied—cooking, smoking, or drying [2]. In dry curing, the curing additives are rubbed onto the surface of a ham, which is then left for ripening and drying, or, in the case of

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

dry-fermented sausages, the ingredients are mixed with the minced meat and fat, stuffed in casings, and left to ferment and dry. Frequently, depending on traditions, the products can be smoked [3].

The acceptability of dry-cured meat products is dependent upon its sensory characteristics, including all aroma, appearance, flavor, texture, aftertaste, and sound properties. Differences among these aspects allow one to distinguish the various products from each other. These aspects are quantified by sensory judges to describe the perceived product attributes [4].

Descriptive sensory analyses are distinguished from other sensory methods in that they give a profile of a product on all its perceived sensory characteristics; therefore, its purpose is to identify and measure the presence or intensity of a particular characteristic [5].

Descriptive sensory analyses are used to relate descriptive sensory data with instrumental or consumer preference measurements. They are also used for quality control, for comparison of product prototypes, and for sensory mapping and product matching [4], as well as for many other uses, including investigating the effects of different ingredients or product changes over storage time. Dijksterhuis and Byrne [6] concluded that a trained set of assessors could be a reliable and valid measure instrument, although this depends on the quality of the sensory training carried out before the profiling. Also, it is difficult to generalize profiling results to a consumer population because sensory profiling is focused on nonaffective parts of food perception.

There are different methods of descriptive analysis, including flavor profile method, texture profile, quantitative descriptive analysis (QDA®), quantitative flavor profile, spectrum method, generic descriptive analysis, and free choice profiling [4,6]. The main differences among these methods are shown in Table 11.1. These methods reflect different philosophies and approaches.

The flavor profile method is a consensus technique in which vocabulary development and rating sessions are carried out during group discussions [4]. The advantage of this method is that the panelists are highly trained and, therefore, are sensitive even to small product differences. The texture profile method allows the description of texture from the first bite through complete mastication and also accounts for the temporal aspects of attributes [4]. The panel is highly trained and attributes are rated on scales anchored with specific food products; some of these have become unavailable or difficult to find outside the United States. The vocabulary used in QDA is a nontechnical everyday language to avoid bias response resulting from using a provided language. Reference standards are only used when a problem exists with a particular term. One limitation is that it is difficult to compare results from this technique between panels or laboratories, and from one time to another [4].

The quantitative flavor profile method focuses on the description of flavor only, using a technical standardized flavor language and reference standards to demonstrate concepts; estimated intensities are highly suitable for cross-cultural and cross-laboratory projects [4]. In the spectrum method there is an extensive use of reference lists, specialized panel training, and scaling procedures; however, as in the texture profile method, the reference products for anchoring attribute intensities are not available outside the United States [4]. Generic descriptive analysis combines the most suitable philosophies and techniques of the various methods, depending on the needs of the project. Finally, free choice profiling uses consumers with their own attribute definitions to define and quantify products.

In general, these methods use a reduced number of trained panelists; the main differences are in the use of vocabulary, attribute references, and the intensity scale. An attribute reference is defined as the background information and reference points that assessors mentally use when choosing words and intensities to describe and quantify perceptions [7]. Without training, assessors use their own, usually different, points of reference to evaluate products, and therefore responses vary widely. All traditional descriptive methods follow a training regimen to establish a common frame of reference. There are various attribute-specific scaling philosophies—universal, product-, or

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 11.1 Methods of Sensory Profiling

Method	*No. of Panelists*	*Vocabulary Development*	*Qualitative Attribute References*	*Training*	*Scale*
Flavor profile method	4–6	Consensus vocabulary obtained through discussions	Technical language Definitions and references only during training	2–3 weeks	Product scale 5-point scale
Texture profile method	10	Only texture	Scale points anchored by specific food products	6–7 months (130 h)	Product scale 13 points
QDA®	10–12	Nontechnical vocabulary	None used, only when there is a problem	10–15 h	Unstructured 15-cm line Relative differences among products
Quantitative flavor profile technique	6–8	Only flavor technical language	Reference standards	2–3 weeks	
Spectrum method®	6–8	Panelists develop their list of attributes with the use of a reference list	References for anchoring attribute intensities different from the product	50–95 h	Universal reference scale unstructured 15 cm line
Generic descriptive analysis		Combine different methods according to their needs			
Free choice profiling		The panelist are consumers, not trained, and they use their own attributes	Able to use a scale and be consumers of the product	No	Unstructured 15-cm line

Source: Adapted from Murray et al., *Food. Res. Int.*, 34, 461–471, 2001; Dijksterhuis, G.B. and Byrne, V., *Crit. Rev. Food Sci.*, 45, 527–534, 2005.

Downloaded From Vet-eBooks.com

attribute-specific—that are based on how the highest intensity of the frame of reference is chosen. In universal scaling, the attribute intensities are rated on an absolute and universal basis. Intensities are established considering all products and intensities to define the highest intensity point on the scale. In product-specific scaling, the attribute intensities are rated only within the product category being studied. Finally, in attribute-specific scaling, each attribute is rated independently from the others within a product, and each attribute has its own scale and intensity references [7].

The development of sensory descriptors or sensory descriptive attributes for dry-cured meat products depends largely on the processing conditions and geographical location, as will be shown. In this chapter are presented the different methodologies applied to dry-cured meat products and the main descriptors that have been defined and used.

11.2 Dry-Fermented Sausages

11.2.1 Sensory Methods Applied to Dry-Fermented Sausages

Dry-fermented sausages vary depending on the raw materials and processing conditions, as well as on geographic locations. Briefly, the minced meat, fat, and additives are mixed and stuffed into casings. Then the sausages are fermented in curing chambers for 1–2 days, then subjected to a ripened process for about 7–90 days depending on the type of product, diameter, and desired flavor. The most common spices and condiments added to dry-fermented sausages are pepper, paprika, mustard, oregano, rosemary, garlic, and onion [8], producing a major contribution to the aroma profile of the product.

The principal sensory profiling methods applied to dry-fermented sausages are generic descriptive analyses, followed by QDA, free choice profiling, and flavor profile (see Table 11.2). In generic descriptive analyses, the number of trained or semitrained panelists has been between 5 and 12, and in most of the studies, the training process was briefly described. The sensory descriptors evaluated were mainly appearance, flavor, and texture descriptors. The scale used varied depending on the work but generally was a 5–10 point intensity scale.

The QDA method was applied exclusively to Spanish dry-fermented sausages using between 10 and 15 trained panelists, and the training sessions were briefly described. Free choice profiling and flavor profiling are also applied to dry-fermented sausages but less frequently (Table 11.2).

However, attribute references were only used by a small number of authors (Table 11.3). A product-specific scale, based on different Italian salamis, was used to evaluate specific flavor attributes, corresponding to the upper extreme of the scale [9]. In the evaluation of French and Spanish dry-fermented sausages, various attribute specific references were used [10,11]. However, these attribute references were included only during the training process to help the panelists to describe the perceptions.

Other sensory analyses have been applied to dry-fermented sausages, mainly acceptability and preference tests (Table 11.4). In both tests, the principal attributes evaluated have been appearance, flavor, and texture, using a large number of consumers.

11.2.1.1 Flavor Descriptors

The flavor descriptors developed for dry-fermented sausages are quite varied, as reflected in Figure 11.1. Depending on their origin, the flavor descriptors can be classified as process- and meat-related flavors and other flavors. Process-related flavors include terms like “hot,” “spice,”

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 11.2 Methods of Sensory Profiling Applied to Dry-Fermented Sausages

No. of Panelists	*Attributes*	*Dry-Fermented Sausage*	*Qualitative Attribute References*	*Training*	*Scale*	*Reference*
Generic Descriptive Analysis						
10 trained	Appearance, flavor, texture	American salami	No references		5 and 7 point	12
5 trained	Flavor, taste	Italian	Product-specific scaling (attributes are based on the own-product scale)	3 sessions	7 points	9
13 semitrained	Appearance, taste, flavor, texture	Italian	No references	2 sessions	1–7 points	13
10 semitrained	Appearance, taste, flavor, texture	Italian (Sicilian salami)	No references	1 session	6-point intensity	14
10 untrained	Appearance, flavor, texture, sensations	Italian	No references		10-point intensity	15
12 trained	Appearance, flavor, taste	Italian	No references		10 point	16
11 trained	Flavor	Sausage	No references A reference sample presented at the beginning of the session	12 sessions	15-cm unstructured line	17
12 trained	Aroma, taste, sensation	French	No references	9 sessions (1.5 h/ session)	20-cm unstructured	18
11 trained	Appearance, taste, flavor, texture	Spanish (chorizo)	No references		7-point intensity	19

(*continued*)

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 11.2 (continued) Methods of Sensory Profiling Applied to Dry-Fermented Sausages

No. of Panelists	*Attributes*	*Dry-Fermented Sausage*	*Qualitative Attribute References*	*Training*	*Scale*	*Reference*
20 semitrained	Appearance, flavor, texture, sensations	Spanish (salchichón)	No references		9-point intensity	20
5 trained	Texture, taste, flavor	Spanish (salchichón)	References Attribute-specific scaling (each attribute has its own reference and scale)	3 sessions	Unstructured 10-point intensity	21
5 trained	Appearance, taste, flavor, texture, sensations	Spanish (salchichón)	Attribute-specific scaling (each attribute has its own reference and scale)	18 h	5-point intensity	11
QDA						
10 trained	Texture	Spanish (chorizo)	No references		5-point intensity	22
10 trained	Appearance, flavor, texture	Spanish (chorizo)	No references		5-point intensity	23
12 trained	Appearance, taste	Spanish (chorizo)	No references Control sample used as reference	3 sessions (1 h/session)	9-point intensity	24

Downloaded From Vet-eBooks.com

12 trained	Flavor, taste, sensations	Spanish (chorizo)	No references Control sample used as reference	3 sessions (1 h/session)	9-point intensity	25
15 trained	Texture, flavor, aroma, sensations	Spanish (salchichón)	No references	120 h	Unstructured 10-cm line	26
Free Choice Profiling						
12 untrained	Appearance, aroma, texture, flavor	Australian salami	No references	7 sessions	Unstructured line (0–100) with end points defined by consensus	27
16 untrained	Appearance, taste, flavor, texture	Spanish (ostrich)	No references		Unstructured 10-cm line scale anchored with weak and strong	28
Flavor Profile						
10 trained	Flavor	French	References for each attribute different from the products	7 sessions	Unstructured	10

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 11.3 Attribute References Used in the Sensory Evaluation of Dry-Fermented Sausages

Virgili et al. [9]		*Rousset-Akrim et al. [10]*		*Ruiz Pérez-Cacho et al. [11]*	
Attribute	*Product-Specific References (Italian Salami)*[a]	*Attribute*	*Attribute-Specific (French)*	*Attribute*	*Attribute-Specific (Spanish)*
Aged	10–month-old salami (pH: 5–5.5, salt: 5–5.5%)	Dry-cured sausage flavor	Dry-cured sausage		
Pungent	Salami (salt: 3–3.5%), proteolysis (20–22%), acetic acid > 0.1%, moisture/protein > 2				
Rancid	Dry-cured ham, external fat				
Buttery	250 mg/kg diacetyl in water	Butter	2,3-Butanedione		
Sweetish	Salami, fat/protein > 2				
Salty	Salami, salt: 7–7.5%			Salty	—
Acid	Salami, pH < 4.5	Vinegar	Acetic acid	Acid	Vinegar, old cottage cheese
		Nutty	Dried fruit (hazelnut)		

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

		Milk	Fresh cow milk		
		Pâté	Paté de campagne		
		Fat	Fresh pork fat		
				Black pepper aroma	Black pepper grounded
				Lactic acid odor	Yogurt
				Mould aroma	1-Octen-3-ol (0.4 mg/L)
				Spices aroma	Mixture of ground nutmeg, anise, cloves, cinnamon, and cumin
				Hardness	Raw frankfurter–American yellow cheese–toasted peanuts
				Initial juiciness	Egg white–cooked ham

[a] Corresponds to the upper extreme of the scale.

Downloaded From Vet-eBooks.com

Table 11.4 Other Sensory Analyses Applied to Dry-Fermented Sausages

Method	*No. of Panelists*	*Attributes*	*Dry-Fermented Sausage*	*Scale*	*Reference*
Acceptability					
Acceptability test	116	Appearance, flavor, tenderness, juiciness, color, overall satisfaction	Salami (USA)	Hedonic	12
Acceptability test	25	Odor, color, texture, taste, acceptability	Spanish	Hedonic	29
Acceptability test	18–20	Color, texture, odor, flavor	Spanish	Hedonic	30,31,32–34
Acceptability test	98		Spanish	Hedonic	35
Preference					
Preference test	279		Spanish		40
Paired preference test	60		Spanish		36
Paired preference test	50–100	Color, aroma, taste, overall quality	Spanish		37–40
Paired comparison test	27	Aroma, color, and taste	Spanish		41,42
Preference ranking test	35	Appearance, taste, texture	Spanish		43

"paprika," "smoky," etc., which result from the addition of spices and condiments or a smoking process during the manufacture of the dry-fermented sausage. These terms were used in regard to sausages from various origins—French [10,18], Spanish [19,25,28], Italian [9,16], and Australian [27]. They varied depending on the condiments added during the processing due to local traditions.

Meat-related flavors are those related to meat constituents, such as lean meat and fat; therefore, the flavor descriptors involved are mainly related to the terms "cured" [26], "aged" [9], "maturation" [13], "rancid" [9,13–17,19,26,28], and "fat" [10,17,18]. Other flavor descriptors also described in Danish and French dry-cured sausages were "vinegar" and "cheese" [10,17,18], although other terms like "mould," "acidity," and "buttery" were also defined in Spanish [11] and Italian [16] sausages.

The principal taste descriptors used in all types of dry-fermented sausages were "bitter," "acid," and "salty" [11,13,14,18,19]. The salty taste comes from the sodium salt added with the

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

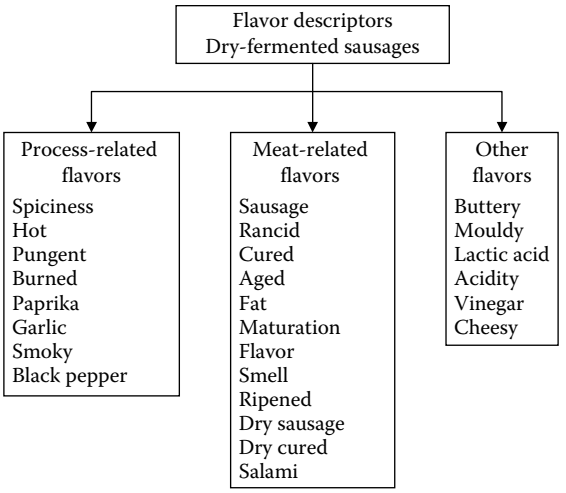


Figure 11.1 Main flavor descriptors used in the sensory analysis of dry-fermented sausages.

other condiments, and the sour or acid taste is due to carbohydrate fermentation, which generates significant amounts of acetic and lactic acids [44]. A few authors described the presence of a "sweetness" taste in Italian [9,16] and Spanish [21,26] sausages, which can be a result of the carbohydrate addition in the manufacture process.

11.2.1.2 Sensations and Texture Descriptors

The most commonly evaluated sensation descriptors were "aftertaste" [15,18,26] (also called "persistence" [19]), "fat mouth feel" [28], and "astringency" [25]. The "aftertaste" sensation may be due to the presence of nucleotides, nucleosides, and free glutamic acid that is commonly generated during processing [45].

Owing to the initial acidification during the fermentation stage, the texture of dry-fermented sausages is considerably affected by coagulated proteins at acid pH. Afterwards, dehydration during ripening, together with a reduction of the water-retention capacity of proteins, contributes to the firmness of the sausage [46]. Therefore, the most common texture descriptors are "hardness" and "juiciness" [11,15,26,28]. Other texture descriptors have been used, including "chewiness" [12,19,22,27], "cohesiveness" [14,22], "elasticity" [13,14], "softness," "fibrousness" [26], and "firmness" [16]. These textural characteristics are usually correlated to ripening time, moisture content, sausage diameter, and initial grinding size [47].

11.2.1.3 Appearance Descriptors

The main appearance descriptors used to evaluate dry-fermented sausages relate to color, using descriptive terms such as "color homogeneity" [12–14,19,23,27,28] and "red intensity" [16], which is due to the reaction of nitrite with myoglobin, producing the red cured color [48]. However, other appearance descriptors are also used, including "fat content" [11,19,27,28], "visual cut appearance," "presence of crust" [11], "particle size" [27], and "slice cohesion" [15,16].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

11.3 Dry-Cured Ham

11.3.1 Sensory Methods Applied to Dry-Cured Hams

Dry-cured ham is a typical cured product processed over a very long time, generally from 3 to 24 months. It is typical in the Mediterranean area (Spanish Serrano or Iberian, French Bayonne, and Italian Parma dry-cured hams) as well as in China (Jinhua ham) and the United States (country-style ham). Generally, dry-cured ham processing consists of three stages—salting, postsalting, and ripening/drying. In the salting stage, the salt containing nitrate and nitrite is rubbed onto the surface of the ham and maintained at refrigerated temperature over several days for salt penetration. Postsalting consists of washing the ham, which is then left at refrigerated temperatures for salt diffusion. Finally, the ripening/drying stage is performed by increasing the temperature and decreasing the relative humidity, favoring the enzymatic activity for flavor development [49].

The sensory profiling methods applied to dry-cured hams are primarily generic descriptive analyses, followed by QDA, free choice profiling, and the spectrum method (Table 11.5). The generic descriptive analysis method was used to describe the sensory characteristics of American, French, Spanish, and Italian dry-cured hams. The number of trained or semitrained panelists used was between 6 and 16, and in most studies the training process was not indicated or briefly described. The sensory descriptors evaluated were mainly appearance, flavor, and texture descriptors. The most common scale used was an unstructured quantitative scale from 0 to 10.

The QDA methodology was mainly applied to Spanish and Italian dry-cured hams (Table 11.2), using between 5 and 14 trained panelists. However, the training process was not indicated, and in only a few cases was previous panel experience indicated. A free choice profiling method was applied to Italian dry-cured ham [50]. Finally, only one study applied the spectrum method to Spanish Serrano dry-cured ham [51]. This methodology is characterized by the use of a universal intensity scale in which references different from the product are used to anchor the intensity values (Table 11.6).

Apart from the use of the universal intensity scale using specific references different from the product [51], only two other works used attribute references [52,53]. A product-specific scale of different dry meats was used to evaluate specific texture descriptors; their intensities corresponded to the upper extreme of the scale [52]. In the evaluation of Italian dry-cured ham, different attribute-specific references were used [53]. However, these attribute references [52,53] were included only during the training process to help the panelists describe their perceptions.

Other sensory analyses have been applied to dry-cured hams, primarily acceptability tests (Table 11.7) used to evaluate the overall acceptability of Spanish dry-cured hams. However, for Italian dry-cured ham another method called "different from control" was applied to evaluate the differences in aspect, aroma, and taste from a control sample [54].

11.3.1.1 Flavor Descriptors

The descriptors developed to describe dry-cured ham flavor are varied, as reflected in Figure 11.2. The process-related flavor descriptors are those related to the ripening/drying stage, as with the terms "aged" [68,78], "dry ham" [53,57], and "cured" [71–76,63–67]. There is not a specific attribute reference for the descriptor "cured." It has been defined as the complex flavor generated during dry-cure processing and can include aroma notes such as buttery, cheesy, etc. [52].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 11.5 Methods of Sensory Profiling Applied to Dry-Cured Hams

No. of Panelists	*Attributes*	*Dry-Cured Ham*	*Qualitative Attribute References*	*Training*	*Scale*	*Reference*
Generic Descriptive Analysis						
10	Texture and flavor	American country ham	No references	Not indicated	Unmarked anchored lines	55
—	Flavor	French	No references	Not indicated	Continuous scoring scale (from 0 to 100)	56
12	Texture, taste, and aroma	French	No references	Not indicated	Ungraduated (10 cm long)	57
12	Appearance, texture, and flavor	Bayonne (French)	No references	Not indicated	Scale from 0 to 10	58
12	Appearance, odor, flavor, and texture	French	No references	Not indicated	7-point discrete scale	59
6	Texture	Spanish	Maximum scale point anchored by specific food product	Previous experience (7 years)	Unstructured quantitative (from 0 to 10)	52,60
14	Appearance, aroma, flavor, and overall quality	Serrano (Spanish)	No references	Not indicated	Unstructured interval	61
16	Appearance, flavor, and texture	Serrano (Spanish)	Reference pictures	Not indicated	Unstructured interval (from 0 to 10)	62
14	Appearance, color, aroma, texture, flavor, and acceptability	Spanish	No references (hams used as references only during training)	6 (1 h sessions)	Structured 9-point scale	63–67

(*continued*)

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 11.5 (continued) Methods of Sensory Profiling Applied to Dry-Cured Hams

No. of Panelists	*Attributes*	*Dry-Cured Ham*	*Qualitative Attribute References*	*Training*	*Scale*	*Reference*
5	Flavor and texture	Spanish	No references	Not indicated	Unstructured quantitative (from 0 to 10)	68,69
12	Appearance, texture, aroma, and flavor	Corsican (Italian)	References for describing attributes	3 sessions	Unstructured scale of 10 cm	53
5	Appearance	Tuscan (Italian)	No references	Not indicated	4 point scale	70
QDA						
12–14	Appearance, texture, aroma, and flavor	Iberian (Spanish)	No references	120 h of training	Unstructured 10-cm line	71–75
6	Appearance, odor, flavor, texture, and overall acceptability	Spanish	No references	Not indicated	Rating scale from 0 to 10	76
5	Texture, flavor, and odor	Spanish	No references	5 years experience	Rating scale from 0 to 10	77

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

5	Flavor	Italian	No references (hams used as references only during training)	6 (1 h sessions)	Rating scale from 0 to 5	78
9	Flavor	Parma (Italian)	No references	Not indicated	Unstructured intensity scale ranging from 0 to 15	79
Free Choice Profiling						
10	Flavor	Parma (Italian)	No references	Untrained	0–9 scale	50
Spectrum Method						
13	Flavor	Serrano (Spanish)	References for anchoring different from the product	50 h	Universal intensity scale	51

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Table 11.6 References Used in the Sensory Evaluation of Dry-Cured Hams

Flores et al. [51]		*Guerrero et al. [52]*[a]		*Coutron-Gambotti et al. [53]*	
Attribute	*Universal Intensity Scale (Spanish)*[b]	*Attribute*	*Product-Specific Scale (Spanish)*	*Attribute*	*Attribute-Specific (French)*
Sweet	1% Sucrose solution (1)	Hardness	2–mm-thick slice obtained from *longissimus lumborum* muscle (30 g of added NaCl per kg of muscle) undergoing a 60% weight loss (moisture 30% and NaCl content 6.5%) during the drying process	Fatty	Fresh pork fat
Cooked wheat	Wheat thins (1)	Pastiness and crumbliness	2-mm-thick slice obtained from *longissimus lumborum* muscle (30 g of added NaCl per kg of muscle) containing 1 g of papain (Profix 100P, 15–20%, Quest Int., Spain) per kg of muscle and undergoing a 30% weight loss during the drying process (at 4°C and HR 65–75%)	Rancid	Rancid pork fat
Oil	Frito Lay potato chips (2)	Adhesivity	External surface of *longissimus lumborum* muscle (30 g of added NaCl per kg of muscle) containing 5 g of papain (Profix 100P, 15–20%, Quest Int., Spain) per kg of muscle applied to the loin surface and undergoing a 30% weight loss during the drying process (at 4°C and HR 65–75%)	Mushroom	1-Octen-3-ol

Downloaded From Vet-eBooks.com

© 2011 by Taylor and Francis Group, LLC

Buttery	Land-O-Lakes margarine (3)			Buttery	2,3-Butanedione
Grape	Grape Kool-Aid (4.5)			Hazelnut	Hazelnut powder
Apple	Mott's natural apple sauce (5.0)			Blue cheese	Isovaleric acid
Orange	Minute Maid orange juice (7.0)			Fruity	Isoamyl acetate (banana)
Grape	Welch's grape juice (10.0)				
Salt	Vlasic kosher dill pickle (12.0)				
Sweet	Frosted pop-tarts (raspberry) (16.5)				
Sweet	Frosted pop-tarts (blueberry) (18.0)				

[a] Corresponds to the maximum value of the scale.
[b] References anchoring attributes intensities showed in parenthesis.

Downloaded From Vet-eBooks.com

Table 11.7 Other Sensory Analyses Applied to Dry-Cured Hams

Method	*No. of Panelists*	*Attributes*	*Dry-Cured Ham*	*Scale*	*Reference*
Acceptability					
Acceptability test	268	Overall acceptability	Spanish	Hedonic	80
Acceptability test	18	Overall acceptability	Spanish	Hedonic	81
Acceptability test	30	Overall acceptability	Spanish	9-point hedonic scale	65
Acceptability test	106	Overall acceptability	Spanish	9-point hedonic scale	82
Method "difference from control"	21	Aspect, aroma, and taste	Parma (Italian)	Linear scale, not different (0) to extremely different (100)	54

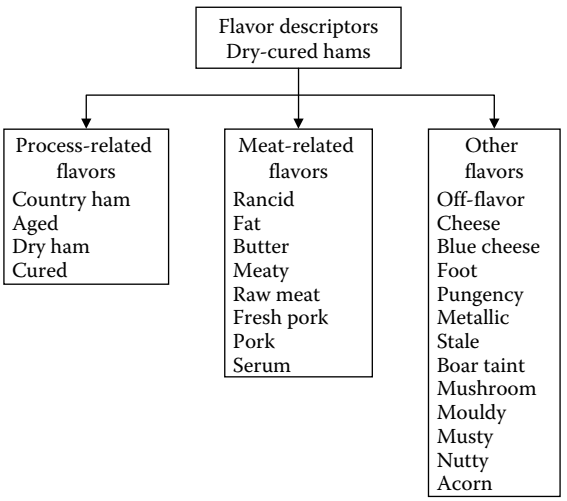


Figure 11.2 Main flavor descriptors used in the sensory analysis of dry-cured hams.

The meat-related flavor descriptors define terms related to the major ham components, lean meat and fat, and their changes during processing. Therefore, the terms used were "fat" [51,53,57,69–72], "rancid" [51,53,56–58,61,63–67,71,72,74,75], "butter" [58,78], "meaty" [56,79], "pork" [51,78], etc. Several of these descriptive terms have specific attribute references, as shown in Table 11.6 for "fat," "rancid," and "butter." The attribute references consisted of food products or, in a few cases, a volatile compound.

Other flavors described in dry-cured hams are related to off-flavors such as "blue cheese" [53], "foot" [58], "boar taint" [51,61,79], metallic [57,68,76], and moldy [63,74,75]. The "boar taint"

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

flavor has been defined as the hormone-like aroma associated with boar meat [51]. A positive flavor has been described as "nutty" [51,61,79], "hazelnut" [53], or "acorn" [63,71–73].

The major taste descriptor used in the sensory evaluation of dry-cured hams is "salty" [51,53,56–58,61,63–68,71–76], but "acid" [51,53,57,61,78] and "bitter" [51,60,61,68,71–76,78] are also used. As indicated previously, the salty taste is due to the sodium chloride added in the salting stage, whereas the bitter taste is generated due to the high proteolysis, which generates the free hydrophobic amino acids and peptides responsible for this bitter taste. On the other hand, the sour taste found in dry-cured hams for which there is no fermentation stage originates from amino acids and short free fatty acids produced during the proteolysis and lipolysis [2].

11.3.1.2 Sensations and Texture Descriptors

The most frequently evaluated sensation descriptor was "aftertaste" [51,61,71–75], which was generally applied to Spanish dry-cured hams in which the long processing time applied produces a high concentration of glutamic acid, which, together with nucleotides, is responsible for this "aftertaste," also called "umami" [51,61]. Also, a "piquant" descriptor has been studied in French [56] and Spanish [60,68,76] dry-cured hams. Finally, a sensation called "metallic" was studied in Spanish dry-cured hams [51]; however, this was classified as a flavor descriptor in French [57] and other Spanish [68,76] hams. This "metallic" sensation was defined as a feeling on the tongue described as flat, and was associated with iron and copper [51].

The acceptability of dry-cured hams is highly dependent on texture parameters. The most frequently evaluated descriptor was "hardness" [52,60,63–68,71–77]; other terms used were "tenderness" [55,58] and toughness [59]. Also, "dryness" was a common descriptor [53,57,59,71–75]; other texture descriptors studied were "fibrousness" [53,57,58,63–68,71–76], "pastiness," "crumbliness," and "adhesiveness" [52,60,63–68,76,77]. To evaluate these texture descriptors in Spanish dry-cured hams, several references were defined by Guerrero et al. [52], using dry-cured salted meat processed under special conditions to give the maximum intensity values of these texture descriptors (Table 11.6).

11.3.1.3 Appearance Descriptors

The main appearance descriptors used to evaluate dry-cured hams are related to the appearance of the lean meat and fat. The cured color generated by the reaction of nitrite with myoglobin [48] is characteristic in hams. About the color of the lean meat the descriptive terms most frequently used were "color homogeneity" [51,58,61,63], "redness" [53,71,72], and "cured color" [64–67]. Regarding the fat portion of the ham, many different papers defined the presence of intramuscular fat as "marbling" [51,53,58,59,61,63,71–75] or "fat color" [58,59,63], although other authors described the "brightness" [53,60] of the hams. On the other hand, a few authors have described the presence of "tyrosine crystals" [51,61] formed in the ham due to the long ripening period, which favors the precipitation of the amino acid tyrosine [51], which is responsible for these white spots.

The sensory quality of dry-cured hams is highly affected by premortem factors (genetic, animal spices, sex, etc.), meat quality, curing salt composition, and rate and extent of the curing process [49]. The sensory evaluation of dry-cured ham is a difficult task due to the presence of different muscles in the ham and to tissue heterogeneity. In this sense, the texture and appearance is highly affected by the slice location, while the flavor is more affected by the length of the process [72].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Up to now the sensory descriptors used in descriptive analysis of dry-cured meat products have many similarities among the bibliographic references. In addition, a few attribute references have been used in descriptive analysis of dry-cured meat products and with different reference systems. In summary, the variety of sensory descriptors depends highly on traditions that affect the specific characteristics of typical dry-cured meat products.

References

1. Flores, J. and Toldrá, F. Curing: Processes and applications. In: *Encyclopedia of Food Science, Food Technology and Nutrition*. R. Macrae, R. Robinson, M. Sadle, and G. Fullerlove, editors, Academic Press, London, U.K., pp. 1277–1282, 1993.
2. Toldrá, F. and Flores, M. Sensory quality of meat products (Chap. 62). In: *Handbook of Food Products Manufacturing*. Y. H. Hui, editor, Wiley, New York, pp. 303–328, 2007.
3. Demeyer, D. I. and Toldrá, F. Fermentation. In: *Encyclopedia of Meat Sciences*. W. Jensen, C. Devine, and M. Dikemann, editors, Elsevier Science Ltd., London, U.K., pp. 467–474, 2004.
4. Murray, J. M., Delahunty, C. M., and Baxter, I. A. Descriptive sensory analysis: Past, present and future. *Food Res Int*, 34:461–471, 2001.
5. Piggot, J. R., Simpson, S. J., and Williams, S. A. R. Sensory analysis. *Int J Food Sci Tech*, 33:7–18, 1998.
6. Dijksterhuis, G. B. and Byrne, V. Does the mind reflect the mouth? Sensory profiling and the future. *Crit Rev Food Sci Nutr*, 45:527–534, 2005.
7. Muñoz, A. M. and Civille, G. V. Universal, product and attribute specific scaling and the development of common lexicons in descriptive analysis. *J Sen Stud*, 13:57–75, 1998.
8. Ordoñez, J. A., Hierro, E. M., Bruna, J. M., and De la Hoz, L. Changes in the components of dry-fermented sausages during ripening. *Crit Rev Food Sci Nutr*, 39:329–367, 1999.
9. Virgili, R. Development of a sensory standard of quality for Parma and S. Daniele hams. *Ind Cons*, 69:222–229, 1994.
10. Rousset-Akrim, S., Martin, J. F., Bayle, M. C., and Berdague, J. L. Comparison between an odour profile and a flavour profile of dry fermented sausages. *Int J Sci Tech*, 32:539–546, 1997.
11. Ruiz Pérez-Cacho, M. P. R., Galan-Soldevilla, H., Leon-Crespo, F., and Molina-Recio, G. Determination of the sensory attributes of a Spanish dry-cured sausage. *Meat Sci*, 71:620–633, 2005.
12. Berry, B. W., Cross, H. R., Joseph, A. L., Wagner, S. B., and Maga, J. A. Sensory and physical measurements of dry fermented salami prepared with mechanically processed beef product and structured soy protein fiber. *J Food Sci*, 44:465–468, 1979.
13. Dellaglio, S., Casiraghi, E., and Pompei, C. Chemical, physical and sensory attributes for the characterization of an Italian dry-cured sausage. *Meat Sci*, 42:25–35, 1996.
14. Moretti, V. M., Madonia, G., Diaferia, C., Mentasti, T., Paleari, M. A., Panseri, S., Pirone, G., and Gandini, G. Chemical and microbiological parameters and sensory attributes of a typical Sicilian salami ripened in different conditions. *Meat Sci*, 66:845–854, 2004.
15. Comi, G., Urso, R., Iacumin, L., Rantsiou, K., Cattaneo, P., Cantoni, C., and Cocolin, L. Characterisation of naturally fermented sausages produced in the north east of Italy. *Meat Sci*, 69:381–392, 2005.
16. Caponio, F., Summo, C., Minervini, F., and Gobbetti, M. Characterisation and quality assessment of ripened sausages in relation to the origin of raw material used. *Eur Food Res Technol*, 222:376–379, 2006.
17. Stahnke, L. H. Dried sausages fermented with staphylococcus-xylosus at different temperatures and with different ingredient levels. 3. Sensory evaluation. *Meat Sci*, 41:211–223, 1995.
18. Viallon, C., Berdague, J. L., Montel, M. C., Talon, R., Martin, J. F., Kondjoyan, N., and Denoyer, C. The effect of stage of ripening and packaging on volatile content and flavour of dry sausage. *Food Res Int*, 29:667–674, 1996.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

19. Fernández-Fernández, E., Vazquez-Oderiz, M. L., and Romero-Rodriguez, M. A. Sensory characteristics of Galician chorizo sausage packed under vacuum and under modified atmospheres. *Meat Sci*, 62:67–71, 2002.
20. Roncales, P., Aguilera, M., Beltran, J. A., Jaime, I., and Peiro, J. M. The effect of natural or artificial casing on the ripening and sensory quality of a mould-covered dry sausage. *Int J Food Sci Technol*, 26:83–89, 1991.
21. Gelabert, J., Gou, P., Guerrero, L., and Arnau, J. Effect of sodium chloride replacement on some characteristics of fermented sausages. *Meat Sci*, 65:833–839, 2003.
22. González-Fernández, C., Santos, E. M., Rovira, J., and Jaime, I. The effect of sugar concentration and starter culture on instrumental and sensory textural properties of chorizo-Spanish dry-cured sausage. *Meat Sci*, 74:467–475, 2006.
23. Valencia, I., Ansorena, D., and Astiasaran, I. Nutritional and sensory properties of dry fermented sausages enriched with n-3 PUFAs. *Meat Sci*, 72:727–733, 2006.
24. Gimeno, O., Astiasaran, I., and Bello, J. A mixture of potassium, magnesium, and calcium chlorides as a partial replacement of sodium chloride in dry fermented sausages. *J Agric Food Chem*, 46: 4372–4375, 1998.
25. Zapelena, M. J., Zalacain, I., Depena, M. P., Astiasaran, I., and Bello, J. Addition of a neutral proteinase from Bacillus subtilis (Neutrase) together with a starter to a dry fermented sausage elaboration and its effect on the amino acid profiles and the flavor development. *J Agric Food Chem*, 45:472–475, 1997.
26. Benito, M. J., Rodriguez, M., Martin, A., Aranda, E., and Cordoba, J. J. Effect of the fungal protease EPg222 on the sensory characteristics of dry fermented sausage "salchichon" ripened with commercial starter cultures. *Meat Sci*, 67:497–505, 2004.
27. Beilken, S. L., Eadie, L. M., Jones, P. N., and Harris, P. V. Sensory and mechanical assessment of the quality of frankfurters. *J Text Stud*, 21:395–409, 1990.
28. Soriano, A., Garcia-Ruiz, A., Gomez, E., Pardo, R., Galan, F. A., and González-Vinas, M. A. Lipolysis, proteolysis, physicochemical and sensory characteristics of different types of Spanish ostrich salchichon. *Meat Sci*, 75:661–668, 2007.
29. Selgas, M. D., Ros, J., and Garcia, M. L. Effect of selected yeast strains on the sensory properties of dry fermented sausages. *Eur Food Res Technol*, 217:475–480, 2003.
30. Bruna, J. M., Hierro, E. M., de la Hoz, L., Mottram, D. S., Fernandez, M., and Ordoñez, J. A. The contribution of *Penicillium aurantiogriseum* to the volatile composition and sensory quality of dry fermented sausages. *Meat Sci*, 59:97–107, 2001.
31. Bruna, J. M., Fernandez, M., Hierro, E. M., Ordoñez, J. A., and de la Hoz, L. Improvement of the sensory properties of dry fermented sausages by the superficial inoculation and/or the addition of intracellular extracts of Mucor racemosus. *J Food Sci*, 65:731–738, 2000.
32. Herranz, B., de la Hoz, L., Hierro, E., Fernández, M., and Ordoñez, J. A. Improvement of the sensory properties of dry-fermented sausages by the addition of free amino acids. *Food Chem*, 91:673–682, 2005.
33. Herranz, B., Fernández, M., de la Hoz, L., and Ordoñez, J. A. Use of bacterial extracts to enhance amino acid breakdown in dry fermented sausages. *Meat Sci*, 72:318–325, 2006.
34. Hoz, L., D'Arrigo, M., Cambero, I., and Ordoñez, J. A. Development of an n-3 fatty acid and alpha-tocopherol enriched dry fermented sausage. *Meat Sci*, 67:485–495, 2004.
35. Guardia, M. D., Guerrero, L., Gelabert, J., Gou, P., and Arnau, J. Consumer attitude towards sodium reduction in meat products and acceptability of fermented sausages with reduced sodium content. *Meat Sci*, 73:484–490, 2006.
36. Flores, M., Durá, M. A., Marco, A., and Toldrá, F. Effect of Debaryomyces spp. on aroma formation and sensory quality of dry-fermented sausages. *Meat Sci*, 68:439–446, 2004.
37. Flores, M., Nieto, P., Ferrer, J. M., and Flores, J. Effect of calcium chloride on the volatile pattern and sensory acceptance of dry-fermented sausages. *Eur Food Res Technol*, 221:624–630, 2005.
38. Bolumar, T., Sanz, Y., Flores, M., Aristoy, M. C., Toldrá, F., and Flores, J. Sensory improvement of dry-fermented sausages by the addition of cell-free extracts from *Debaryomyces hansenii* and *Lactobacillus sakei*. *Meat Sci*, 72:457–466, 2006.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

39. Marco, A., Navarro, J. L., and Flores, M. The influence of nitrite and nitrate on microbial, chemical and sensory parameters of slow dry fermented sausage. *Meat Sci*, 73:660–673, 2006.
40. Marco, A., Navarro, J. L., and Flores, M. Quantitation of selected odor-active constituents in dry fermented sausages prepared with different curing salts. *J Agric Food Chem*, 55:3058–3065, 2007.
41. Sanz, Y., Vila, R., Toldrá, F., and Flores, J. Effect of nitrate and nitrite curing salts on microbial changes and sensory quality of non-fermented sausages. *Int J Food Microbiol*, 42:213–217, 1998.
42. Navarro, J. L., Nadal, M. I., Nieto, P., and Flores, J. Effect of nitrate and nitrite curing salts on the generation and oxidation of fatty acids in non-fermented sausages. *Eur Food Res Technol*, 212:421–425, 2001.
43. Flores, J., Marcus, J. R., Nieto, P., Navarro, J. L., and Lorenzo, P. Effect of processing conditions on proteolysis and taste of dry-cured sausages. *Z Lebens Unters Forsch A/Food Res Technol*, 204:168–172, 1997.
44. Lücke, F. K. Fermented sausages. In: *Microbiology of Fermented Foods*. B. J. B. Wood, editor, Elsevier Applied Science Pub., London, U.K., pp. 41–81, 1985.
45. Durá, M. A., Flores, M., and Toldrá, F. Effect of *Debaryomyces* spp. on the proteolysis of dry-fermented sausages. *Meat Sci*, 68:319–328, 2004.
46. Talon, R., Leroy-Sétrin, S., and Fadda, S. Bacterial starters involved in the quality of fermented meat products. In: *Research Advances in the Quality of Meat and Meat Products*. F. Toldrá, editor, Research Signpost, Trivandrum, India, pp. 175–191, 2002.
47. Acton, A. C. The chemistry of dry sausages. *Proc. Annual Reciprocal Meat Conf,* 30:49–62, 1977.
48. Pegg, R. B. and Shahidi, F. *Nitrite Curing of Meat*. Food & Nutrition Press, Trumbull, CT, pp. 67–104, 2000.
49. Toldrá, F. and Flores, M. The role of muscle proteases and lipases in flavor development during the processing of dry-cured ham. *CRC Crit Rev Food Sci Nutr*, 38:331–352, 1998.
50. Parolari, G. Taste quality of Italian raw ham in a free-choice profile study. *Food Qual Pref*, 5:129–133, 1994.
51. Flores, M., Ingram, D. A., Bett, K. L., Toldrá, F., and Spanier, A. M. Sensory characteristics of Spanish "Serrano" dry-cured ham. *J Sen Stud*, 12:169–179, 1997.
52. Guerrero, L., Gou, P., and Arnau, J. The influence of meat pH on mechanical and sensory textural properties of dry-cured ham. *Meat Sci*, 52:267–273, 1999.
53. Coutron-Gambotti, C., Gandemer, G., Rousset, S., Maestrini, O., and Casabianca, F. Reducing salt content of dry-cured ham: Effect on lipid composition and sensory attributes. *Food Chem*, 64:13–19, 1999.
54. Pastorelli, G., Magni, S., Rossi, R., Pagliarini, E., Baldini, P., Dirinck, P., van Opstaele, F., and Corino, C. Influence of dietary fat on fatty acid composition and sensory properties of dry-cured Parma ham. *Meat Sci*, 65:571–580, 2003.
55. Harmon, C. J., Means, W. J., and Kemp, J. D. Bind, sensory and chemical-properties of restructured dry-cured hams. *J Food Sci*, 57:322–324, 1992.
56. Berdague, J. L., Bonnaud, N., Rousset, S., and Touraille, C. Influence of pig crossbreed on the composition, volatile compound content and flavor of dry cured ham. *Meat Sci*, 34:119–129, 1993.
57. Buscailhon, S., Berdague, J. L., Bousset, J., Cornet, M., Gandemer, G., Touraille, C., and Monin, G. Relations between compositional traits and sensory qualities of French dry-cured ham. *Meat Sci*, 37:229–243, 1994.
58. Lebret, B., Massabie, P., Granier, R., Juin, H., Mourot, J., and Chevillon, P. Influence of outdoor rearing and indoor temperature on growth performance, carcass, adipose tissue and muscle traits in pigs, and on the technological and eating quality of dry-cured hams. *Meat Sci*, 62:447–455, 2002.
59. Fernandez, X., Gilbert, S., and Vendeuvre, J. L. Effects of halothane genotype and pre-slaughter treatment on pig meat quality. Part 2. Physico-chemical traits of cured-cooked ham and sensory traits of cured-cooked and dry-cured hams. *Meat Sci*, 62:439–446, 2002.
60. Arnau, J., Guerrero, L., and Gou, P. Effects of temperature during the last month of ageing and of salting time on dry-cured ham aged for six months. *J Sci Food Agric*, 74:193–198, 1997.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

61. Armero, E., Flores, M., Toldrá, F., Barbosa, J. A., Olivet, J., Pla, M., and Baselga, M. Effects of pig sire type and sex on carcass traits, meat quality and sensory quality of dry-cured ham. *J Sci Food Agric*, 79:1147–1154, 1999.
62. Soriano, A., Quiles, R., Mariscal, C., and Garcia-Ruiz, A. Pig sire type and sex effects on carcass traits, meat quality and physicochemical and sensory characteristics of Serrano dry-cured ham. *J Sci Food Agric*, 85:1914–1924, 2005.
63. Garcia-González, D. L., Roncales, P., Cilla, I., del Rio, S., Poma, J. P., and Aparicio, R. Interlaboratory evaluation of dry-cured hams (from France and Spain) by assessors from two different nationalities. *Meat Sci*, 73:521–528, 2006.
64. Cilla, I., Altarriba, J., Guerrero, L., Gispert, M., Martinez, L., Moreno, C., Beltran, J. A., Guardia, M. D., Diestre, A., Arnau, J., and Roncales, P. Effect of different Duroc line sires on carcass composition, meat quality and dry-cured ham acceptability. *Meat Sci*, 72:252–260, 2006.
65. Cilla, I., Martinez, L., Beltran, J. A., and Roncales, P. Dry-cured ham quality and acceptability as affected by the preservation system used for retail sale. *Meat Sci*, 73:581–589, 2006.
66. Cilla, I., Martinez, L., Beltran, J. A., and Roncales, P. Effect of low-temperature preservation on the quality of vacuum-packaged dry-cured ham: Refrigerated boneless ham and frozen ham cuts. *Meat Sci*, 73:12–21, 2006.
67. Cilla, I., Martinez, L., Guerrero, L., Guardia, M. D., Arnau, J., Altarriba, J., and Roncales, P. Consumer beliefs and attitudes towards dry-cured ham and protected designation of origin Teruel ham in two Spanish regions differing in product knowledge. *Food Sci Tech Int*, 12:229–240, 2006.
68. Serra, X., Grebol, N., Guardia, M. D., Guerrero, L., Gou, P., Masoliver, P., Gassiot, M., Sarraga, C., Monfort, J. M., and Arnau, J. High pressure applied to frozen ham at different process stages. 2. Effect on the sensory attributes and on the colour characteristics of dry-cured ham. *Meat Sci*, 75:21–28, 2007.
69. Guerrero, L., Guardia, M. D., and Arnau, J. Propuesta metodológica de análisis sensorial en jamón curado: Criterios a considerar y sistemas de validación. *Proceedings 3er Congreso Mundial del Jamón*, Teruel, Spain, pp. 187–196, 2005.
70. Franci, O., Pugliese, C., Acciaioli, A., Bozzi, R., Campodoni, G., Sirtori, F., Pianaccioli, F., and Gand Lini, G. Performance of Cinta Senese pigs and their crosses with Large White. 2. Physical, chemical and technological traits of Tuscan dry-cured ham. *Meat Sci*, 76:597–603, 2007.
71. Ruiz, J., García, C., Muriel, E., Andres, A. I., and Ventanas, J. Influence of sensory characteristics on the acceptability of dry-cured ham. *Meat Sci*, 61:347–354, 2002.
72. Ruiz, J., Ventanas, J., Cava, R., Timon, M. L., and García, C. Sensory characteristics of Iberian ham: Influence of processing time and slice location. *Food Res Int*, 31:53–58, 1998.
73. Ventanas, S., Ventanas, J., Tovar, J., García, C., and Estevez, M. Extensive feeding versus oleic acid and tocopherol enriched mixed diets for the production of Iberian dry-cured hams: Effect on chemical composition, oxidative status and sensory traits. *Meat Sci*, 77:246–256, 2007.
74. Andres, A. I., Cava, R., Ventanas, J., Muriel, E., and Ruiz, J. Lipid oxidative changes throughout the ripening of dry-cured Iberian hams with different salt contents and processing conditions. *Food Chem*, 84:375–381, 2004.
75. Carrapiso, A. I., Bonilla, F., and García, C. Effect of crossbreeding and rearing system on sensory characteristics of Iberian ham. *Meat Sci*, 65:623–629, 2003.
76. Sarraga, C., Guardia, M. D., Diaz, I., Guerrero, L., García-Regueiro, J. A., and Arnau, J. Nutritional and sensory quality of porcine raw meat, cooked ham and dry-cured shoulder as affected by dietary enrichment with docosahexaenoic acid (DHA) and alpha-tocopheryl acetate. *Meat Sci*, 76:377–384, 2007.
77. Gou, P., Guerrero, L., and Arnau, J. Sex and crossbreed effects on the characteristics of dry-cured ham. *Meat Sci*, 40:21–31, 1995.
78. Careri, M., Mangia, A., Barbieri, G., Bolzoni, L., Virgili, R., and Parolari, G. Sensory property relationships to chemical-data of Italian-type dry-cured ham. *J Food Sci*, 58:968–972, 1993.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

79. Hinrichsen, L. L. and Pedersen, S. B. Relationship among flavor, volatile compounds, chemical-changes, and microflora in Italian-type dry-cured ham during processing. *J Agric Food Chem*, 43: 2932–2940, 1995.
80. Bañon, S., Gil, M. D., and Garrido, M. D. The effects of castration on the eating quality of dry-cured ham. *Meat Sci*, 65:1031–1037, 2003.
81. Martin, A., Cordoba, J. J., Aranda, E., Cordoba, M. G., and Asensio, M. A. Contribution of a selected fungal population to the volatile compounds on dry-cured ham. *Int J Food Microbiol*, 110:8–18, 2006.
82. Flores, M., Barat, J. M., Aristoy, M. C., Peris, M. M., Grau, R., and Toldrá, F. Accelerated processing of dry-cured ham. Part 2. Influence of brine thawing/salting operation on proteolysis and sensory acceptability. *Meat Sci*, 72:766–772, 2006.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

FISH AND SEAFOOD PRODUCTS

III

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 12

Quality Assessment of Fish and Fishery Products by Color Measurement

Reinhard Schubring

Contents

12.1 Introduction 199
12.2 Instrumentation 201
12.3 Novel Method of Color Evaluation 203
12.4 Color Measurement on Fish and Fishery Products 204
12.4.1 Aquaculture 204
12.4.2 Fish Mince, Surimi, and Surimi-Based Products 207
12.4.3 Processing Effect on Color of Fish and Fishery Products 207
12.4.3.1 Refrigerated and Frozen Storage 207
12.4.3.2 Thermal Processing (Heating and Smoking) 207
12.4.3.3 High-Pressure Processing 207
12.5 Summary 211
References 221

12.1 Introduction

We perceive the world in which we live by our five senses—vision, hearing, touch, taste, and smell, of which the sense of vision is usually the first used in detecting events and objects around us in the visual world. The process of seeing comprises many cooperating activities, first detected by our eyes

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and then interpreted by our brain, recognition of movement and location of object, relationship of objects to their surroundings, the intensity and quality of the light, and the color appearance of object or events in the visual scene [1]. Scientific understanding of the processes involved in determining color appearance has been elucidated in the last two to three centuries. The experiments in mixing colors performed during this time period clearly demonstrated that people with normal color vision must have at least three retinal pigments in their eyes, detecting the short, medium, and long waves of the visible spectrum. The first truly functional system for measuring color as specified by the Commission Internationale de l'Eclairage (CIE) was the so-called CIE 1931 2° visual field system of color measurement. Since then, many improvements have been incorporated into the system to make it almost visually uniform and this research continues [1].

With the development of the computer, complex color measurements and calculations are now routinely used in research and food industry for studies of food functionality, for product ingredient standardization, and for process control. Three interacting factors are required for the measurement of the color appearance of any object in a scene. These are an understanding of the human visual process, the effect of light on objects in their environment, and the nature of the materials observed [1]. The CIE system of color measurement transforms the reflection or transmission spectrum of the object into a three-dimensional color space using the spectral power distribution of the illuminant and the color-matching functions of the standard observers. The original 1931 CIE Y, x, y system of color measurement is not visually uniform. Constant hue and chroma are distorted and equal visual distances increase severalfold from purple-red to green. Near-uniform color spaces of practical importance are the Hunter and the CIELUV and CIELAB spaces. The CIE $L^*a^*b^*$ also known as CIELAB has generally replaced the Hunter space in industrial application. The coordinates $L^*a^*b^*$ serve to define the locations of any color in the uniform color space. Color terms can be divided into the subjective and the objective. The subjective terms, i.e., the psychosensorial, are brightness, lightness, hue, saturation, chroma, and colorfulness. Colorfulness is that aspect of visual sensation according to which an area appears to exhibit more or less chromatic color. Although hue is easily understood as that attribute described by color names such as red, green, purple, and the like, the difference between saturation and chroma is less easy to comprehend. Saturation is colorfulness judged in proportion to its brightness, whereas chroma is colorfulness relative to the brightness of its surroundings. A similar difference exists between lightness and brightness. Lightness is relative to brightness. Lightness is unaffected by the level of illumination because it is the proportion of the light reflected, whereas the sensation of brightness increases with an increase in the level of illumination. The objective terms, i.e., the psychophysical, are related to the stimulus and evaluated from spectral power distribution, the reflectance or transmittance of the object, and observer response. They provide the basis for the psychometric qualities that correspond more nearly to those perceived [1]. For CIELAB space the terms are lightness L^*, hue $h^* = \tan^{-1}(a^*/b^*)$, and chroma $C^* = (a^{*2} + b^{*2})^{1/2}$. CIELAB total color difference can be expressed either as the coordinates of color space or as the correlates of lightness, chroma, and hue.

$$\Delta E^* = \left[\left(\Delta L^{*2}\right) + \left(\Delta a^{*2}\right) + \left(\Delta b^{*2}\right)\right]^{1/2}$$

or

$$\Delta E^* = \left[\left(\Delta L^{*2}\right) + \left(\Delta C^{*2}\right) + \left(\Delta H^{*2}\right)\right]^{1/2}$$

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Color is the perception that results from the detection of light after it has interacted with an object. The perceived color of an object is affected by three entities: the physical and chemical composition of the object, the spectral composition of the light source illuminating the object, and the spectral sensitivity of the viewer's eye. As everyone is sensitive to the color of foods, appetite is stimulated or dampened in almost direct relation to the observer's reaction to color. The color we see clearly indicates the flavor we will taste [2]. For food products, the consumers often assess the initial quality of the product by its color and appearance. In food processing and cooking, color serves as a cue for the doneness of foods and is correlated with changes of aroma and flavor. For example, color or lightness such as the lightness of canned tuna is important for identity and quality grading. In general, color and appearance affect the consumer's perceptions of other sensory modalities [3]. The appearance of fish and meat products is an essential factor according to which the consumers judge their acceptance [4]. However, the color of food is not stable, in that it changes with decreasing freshness. The appearance of a newly landed fish is unforgettable, in that the interplay of the subtle shades of beautiful colors makes it a joy to behold and irresistible as an item of food. Just a few hours after death, though, it begins to look less obviously attractive, and its now "ordinary" colors are much more familiar to the majority of the public [5].

12.2 Instrumentation

Photoelectric color-measuring instruments can be divided into two classes: trichromatic colorimeters and spectrophotometers. Colorimeters are tristimulus (three-filtered) devices that make use of red, green, and blue filters, which emulate the response of the human eye to light and color. In some quality control applications, these tools represent the lowest cost answer. The more modern tristimulus instruments are linked to computers with automatic compensation and the provision of a number of color spaces. A colorimeter uses a light source to light the specimen being measured. The light reflected off the object then passes through the glass filters to simulate the standard observer functions for a particular illuminant. A photodetector beyond each filter then detects the amount of light passing through the filters. These signals are then displayed as *X*, *Y*, and *Z* values. The Chroma Meter CR-300 (Figure 12.1) used for own measurements offers 8 mm diameter measuring area and diffuse illumination/0° viewing geometry for a wide variety of applications. The measuring head of the CR-300 uses diffuse illumination/0° viewing geometry (specular component included) to provide measurements of a wide variety of surfaces that correlate well with color as seen under diffuse lighting conditions. A pulsed xenon arc (PXA) lamp



(a) (b) (c) (d)

Figure 12.1 Selection of instruments for color measurement on fish and fishery products. (a) Color Reader CR-10, (b) HunterLab MiniScan XE Plus, (c) Chroma Meter CR-300, and (d) spectral color meter spectro-pen®.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

inside a mixing chamber provides diffuse, uniform lighting over the 8 mm diameter specimen area. Only the light reflected perpendicular to the specimen surface is collected by the optical-fiber cable for color analysis. As illuminant condition D65 and for calibration purposes a white standard CR-A43 were used. Use of the computer software ChromaControl C (release 2.04) allows the easy calculation of hue and chroma.

Besides the aforementioned instrument that is widely used for color measurement on fish and fishery products there are further instruments available that can be used for the same purpose. For example, the Color Reader CR-10 (from Konica Minolta) is a very compact, battery-powered, handheld portable colorimeter (tristimulus type) for quick color control (Figure 12.1). At first, simply measure the target and then the sample. After one second the color difference—expressed in $L^*a^*b^*$ and ΔE^* or $L^*C^*H^*$ and ΔE^*—will appear on the LCD screen. The measuring area of 8 mm in addition to the 8/d geometry allows for universal use in a wide variety of applications. All measurements are taken under the conditions of standard illuminant D65 and 10° observer. To get a printout of the readings, the CR-10 can be connected to an external printer.

Spectrophotometer is the most accurate instrument for measuring color. It uses a light source to light the specimen being measured. The light reflected by the object then passes to a grating that breaks it into the spectrum. The spectrum falls onto a diode array that measures the amount of light at each wavelength. This spectral data is then sent to the processor where it is multiplied together with data table values for the selected CIE illuminant and the 2° or 10° standard observer functions to the X, Y, and Z values. These are further transformed to the CIELAB values L^*, a^*, b^* by using the following equations:

$$L^* = 116\left(Y/Y_n\right)^{1/3} - 16$$

$$a^* = 500\left[\left(X/X_n\right)^{1/3} - \left(Y/Y_n\right)^{1/3}\right]$$

$$b^* = 200\left[-\left(Y/Y_n\right)^{1/3} - \left(Z/Z_n\right)^{1/3}\right]$$

Own color measurements on fish samples were carried out with the spectral color meter spectro-pen® (Dr. Lange, Düsseldorf, Germany). This is a colorimeter (Figure 12.1) operating on the spectral method described in DIN 5033 using the 45°/0° circular viewing geometry, i.e., the sample is illuminated with polychromatic light encircling it at an angle of 45°, with the optical unit observing the reflected light from a horizontal angle (0°) toward the sample surface. Spectro-pen is a genuine grating colorimeter measuring the visible spectral range (400–700 nm) at intervals of 10 nm. A 10°-standard observer function and D65 as illuminant were used (light source: polychromatic with tungsten lamp). The PC-software "spectral–QC" allows state-of-the-art data processing. Before measuring each lot the colorimeter was calibrated against a white standard (LZM 224). A widely used spectrophotometer in fish processing and research is the HunterLab MiniScan XE Plus 45/0 LAV spectrophotometer (Figure 12.1) with the special glass or polycarbonate-covered nose. Up to 99 product setups can be stored in memory. Moreover, 999 tristimulus sample readings or 500 spectral data readings can be stored for later recall or output to a computer or printer. Each setup includes color scale, illuminant, observer, indices, standard type, pass/fail tolerances, and sample averaging. Setups can be linked together for easy measurement under different illuminants or color scales. Flexibility is the cornerstone of each HunterLab portable system. Both

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

45°/0° and sphere (diffuse/8°) geometries are available. Small, large, smooth textured, and many other types of samples can easily be measured. The LCD screen displays numerical and graphical data with automatic storage and retrieval of tristimulus or spectral data. For even greater capability, MiniScan XE Plus can be used with a PC and EasyMatch® QC or EasyMatch® Formulation software. Fish sample that is at least 25 mm thick for steaks, fillets, and patties or 12.5 mm thick for breaded products should be selected as a prerequisite for color measurement.

The precision of predicting color parameters from one instrument to another varied with food commodity. The type of sample seemed to have a larger effect on the precision of the measurement than the size of the instrument's measuring area. The variation from one instrument to another was found to be systematic and can be described by linear regression. The regression can be used to predict color values expected from one instrument with those obtained from another. The precision of prediction will increase with increased homogeneity of the food samples [6]. When instrumental color measurements of raw salmon flesh were performed by one tristimulus filter colorimeter and two spectrophotometers, it was found that the instruments gave different values in absolute terms, based on the sampling conditions. The highest correlation between astaxanthin content and instrumental color reading were obtained for the a^* and chroma values of the spectrophotometers when sampling on 1 cm thick cutlets on white background [7]. After a comparison between a tristimulus colorimeter (Minolta CR 200) and two spectrophotometers (CM-508i and CM-2002) it was concluded that reproducible and objective measurements expressed in the CIE system were obtained with all the three instruments. A strong correlation was found between the CR 200 and each of the two spectrophotometers. However, absolute values found with the CR 200, especially for b^*, differed from values obtained with the two spectrophotometers [8].

12.3 Novel Method of Color Evaluation

Image features, i.e., color, size, shape, and texture, have been extensively applied in the food industry for quality evaluation and inspection of a wide variety of food. Color features are effective tools for indicating the reconstruction of components of food products during processing.

Three different types of color spaces, hardware orientated, human orientated, and instrumental, are generally used for the extraction of color features. Hardware-orientated spaces are preferable for observing small changes in the color of food products during processing. With the remarkable development of computer hardware, it might become realistic to employ the whole image data as input features, which might be an exceptional indicator of food qualities [9]. Very recently, automated image analysis methods have been presented that were able to describe quality properties, such as area of the cutlet, dorsal fat depot, red muscle, fat percentage, and color from a large number of scanned images of rainbow trout cutlets. It is also evident that it is possible to produce the images of cutlets of adequate quality for image analysis using a simple flatbed scanner [7]. For this purpose, no elaborate lighting regime is necessary [10]. An image-acquisition system was recently presented that allows the obtaining of digital images in $L^*a^*b^*$ color units for each pixel of the digital RGB image. Five models were built that were able to measure color in $L^*a^*b^*$ units and simultaneously measure the color of each pixel on the target surface. This is not the case with conventional colorimeters. The best results were achieved with the quadratic and neural network model [11].

A more easy, performable method has been proposed that uses a combination of digital camera, computer, and graphic software to measure and analyze the surface color of food products [12]. Measuring color, particularly in the $L^*a^*b^*$ space, provides a better statistical discrimination between the groups of fish studied than sensory analysis. In fact, although in agreement with the

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

results of the panel, the colorimetric method can distinguish all of the groups in terms of the mean color and the heterogeneity of color. The very high degree of precision of these results provides an understanding of the effect of the drying processes on the color of the different samples [13]. However, it became obvious that the determination of only one quality attribute was not sufficient. Correct classification based on experimental variables measured by discriminant function analysis was poor for color data alone, acceptable for electronic nose data alone, and excellent with these data combined [14]. Combining the data from the various sensors improves the estimate of the freshness of fish [15]. To demonstrate this, color, texture, and electronic nose measurements were selected and their calibrated outputs combined to construct an Artificial Quality Index (AQI) [16]. It was reported that machine vision is able to differentiate and quantify color distributions in fish samples with uneven color. In the case of fresh tuna, the hue values offered less variability and more monotonous changes with storage time. Color of fresh tuna exposed to 4% CO for 48 h remained unchanged with refrigerated storage time. The color of control sample did change substantially and turned brown [17].

A new index, named Entire Color Index (ECI), was developed to express h^* and C^*, which as combined variables cannot be considered separately. ECI was calculated as $ECI_i = C^* \cos(h_i - h_{mean})$. In all species there was a remarkable dorsoventral gradient in mean L^* and h^*, with the ventral area being statistically significant and brighter than the dorsal one. ECI value was species specific but did not show any statistically significant dorsoventral gradient, with the exception of *Pagrus pagrus*. Storage time affected L^* and h^* only in the dorsal skin area. However, the effect of storage on ice was better reflected in mean ECI value, which showed a marked decrease from day 3 to day 7 in both the dorsal and the ventral skin area. It is concluded that the results provide data for a nonsubjective determination of skin color pattern and show that ECI offers a good index of the actual color in a meaningful and objective way [18].

12.4 Color Measurement on Fish and Fishery Products

In contrast to warm-blooded meat, reports on color measurements taken on fish and/or fishery products are harder to find in books dealing with the color of foods [1,19–24]. Color measurement on fresh meat [1] is explained as a typical example for muscle foods, modeling color stability is discussed on fresh beef [25]. Therefore, the aim of this chapter is to give an overview on the importance and application of color measurement on fish and fishery products. The following main areas of application of color measurements are considered: aquaculture, fish mince, surimi, and surimi-based products, processing effect on color of fish and fishery products (refrigerated and frozen storage, thermal processing, heating and smoking), and high-pressure processing.

12.4.1 Aquaculture

For a long time color measurements performed in this field have been dominated by those taken on farmed Atlantic salmon. Here, traditionally color scales were used by experienced inspectors and are still in use together with up-to-date instrumentation for color measurements [26]. At present, besides the still important salmonides other fish species used for farming are subject to color measurement as well as the comparison between farmed species and their wild counterparts. Table 12.1 provides a brief review of the literature under the aspect of aquaculture.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.1 Color Measurements in the Field of Aquaculture

Task	*Effects on Color*	*References*
Spawning migration and color in chum salmon	*L* increased while *a*, *b*, and *a*/*L* decreased with increasing maturity	[27]
Muscle carotenoid content and color of rainbow trout	Increased pigmentation caused increase in *C** and reduced *h** and *L**	[28]
Carotenoid concentration in diet	Increased concentration led to increased *a**, *b**, and *C**, and decreased *L** and *h**	[29]
Influence of rearing temperature	Arctic char reared at 10°C had higher *a** than those reared at 15°C	[30]
Influence of feeding on pigmented diets on color of Arctic char muscle	Deposition of carotenoids in flesh resulted in decrease in *L* and increase in *a* and *b*	[31]
Color differences between farmed and wild fish	Wild and farmed pikeperch were very similar in *L** and *a**, *b** value of wild fish was significantly lower	[32]
Influence of location at which measurements were taken on rainbow trout	Effect was highly significant on *L**, *C**, and *h**. Order found was: data from tail > data from head part > data from middle part	[33]
Effect of dietary fat level on flesh color of Atlantic salmon	*a** and *b** were higher in salmon fed high fat diets than in those fed medium fat diets	[34]
Effect on flesh color of commercial and experimental slaughtering techniques	Bleeding in ice slurry, whole body electrical treatment, and percussion were compared. Fish killed by electricity had higher *a** and lower *L** values. No differences in *b** were among samples	[35]
Influence of muscle activity on color in Atlantic salmon	Electrically stimulated fish had significant higher *a** and *C** than stressed and rested fish, but there were almost no difference between groups in *L** and *h**	[36]
Influence of slaughtering under high- and low-stress conditions	In farmed Atlantic salmon were no significant differences found in *L**, but *a** and *b** were higher under high-stress	[37]
Comparison in fillet color of diploid and triploid fish	Color of salmon triploids reared in seawater was lower in *L** and higher in *a**. However, shi drum triploids were higher in *L** than diploids. After cooking difference disappeared	[38,39]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.1 (continued) Color Measurements in the Field of Aquaculture

Task	*Effects on Color*	*References*
Influence of rigor mortis on fillet color of Atlantic salmon	Pre-rigor fillet cuts improved color characteristics (lower L^*, higher a^*, and b^* values) when compared to post-rigor	[40]
Effect of pre-rigor filleting of wild and farmed cod on lightness	Time of filleting did not affect L^* of the cut surface measured on day 10 after slaughter	[41]
Influence of duration photoperiods on skin color of gilthead sea bream	Only L^* differed significantly between treatments. Fish reared under permanent light displayed highest values	[42]
Diet supplementation with two carotenoids on skin color	Shrimp shell meal diets enhanced reddish h^* and C^* values. L^* of red porgy skin was not influenced	[43]
Rearing conditions of European catfish fed natural (NF) and formulated (FF) feed	Fish were reared on NF in earthen ponds and on FF in recirculating systems. Only a^* was significantly influenced, being lower in fish fed FF	[44]
Farming conditions on color of raw fillets of European catfish	The shorter the farming time, the lighter the fillets, a high water temperature produced yellower and greener fillets	[45]
Comparison of farmed and wild yellow perch	Farmed yellow perch had higher L^* and wild perch higher a^*	[46]
Effect of diets supplemented with astaxanthin and saponified red chili extract on rainbow trout	Raw fillets showed decrease in L^*, h^*, and C^* and increase in a^* and b^* as diet feeding time increased. Frozen fillets showed decrease in L^* and h^* and increase in a^*, b^*, and C^*. During smoking L^* and a^* did not change and the other values increased	[47]
Influence of cage color and light environment on skin color of Australian snapper	Skin L^* value was much higher in fish held in white than in black cages but was not affected by light environment	[48]
Comparison of crustacean meals with fish meal diet on color of salmon	Highest L^* was obtained for fish meal diet and significant lower L^* were found for crustacean meal diets	[49]
Rearing conditions of wild perch fed natural (NF) and farmed perch fed formulated (FF) feed	a^* was higher and b^* was lower in wild perch, both differences were significant. L^* was not different	[50]
Feasibility of adding astaxanthin as source of red color directly during processing of pastes	Linear regression relationships were found for CIE L^*, a^*, h^*, and astaxanthin content (Ax, mg/kg): $L^* = -0.37\text{Ax} + 76$, $a^* = 0.56\text{Ax} - 2.7$, $h^* = -1.53\text{Ax} + 98$	[51]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

12.4.2 Fish Mince, Surimi, and Surimi-Based Products

The second major area in which color measurements are frequently used is characterized by the comminution of fish muscle and steps to restructure the comminuted muscle to fish muscle analogs mainly by heating. The gel formation necessary to achieve the goal is dependent on the functionality of muscle proteins and is supported by the addition of substances that are able to support gel formation. Most of these technological steps include characteristic color changes of fish muscle. Therefore, it is no wonder that color measurements have been applied at an early stage. In the three relevant textbooks dealing with surimi [52–54], color measurements on surimi gels are highlighted or treated in special chapters [54]. Whiteness (WS), as an index for the general appearance of a surimi gel, has been introduced and can be calculated as

$$\text{Whiteness} = L^* - 3b^* \text{ or whiteness} = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{0.5}$$

Table 12.2 displays briefly a number of relevant papers that characterize the importance of performing instrumental color measurements in this area to evaluate the quality of products.

12.4.3 Processing Effect on Color of Fish and Fishery Products

12.4.3.1 Refrigerated and Frozen Storage

Chilling and freezing are two processing steps for short- and long-term preservation of newly caught fish that influence the color of skin and flesh to a large extent. Therefore, as briefly shown in Tables 12.3 and 12.4, numerous papers on color measurement have been published.

12.4.3.2 Thermal Processing (Heating and Smoking)

As early as 1968, a paper has been published on instrumental color measurement taken on radiation-sterilized pre-fried cod and halibut patties. The breaded pre-fried products were irradiated at 4.5 Mrad, stored for 12 months at 22°C, and evaluated by color reflectance measurement. Pre-fried patties became lighter in color after irradiation. The halibut patties were lighter than the cod patties initially, after irradiation and after storage [123]. The research on colorimetry of salmon has dealt mainly with the color of the canned product. An overview on early activities in this respect has been given in [127]. Since then the effects of thermal processing on color of fish have been extensively investigated. Results of these researches are displayed in Table 12.5.

12.4.3.3 High-Pressure Processing

Besides traditional technologies, the modern ones are more and more on the agenda of fish processing. An example of the practical use of minimal processing in the form of the application of high-pressure processing can be seen in the processing of oysters. HP-treated oysters had higher L values than untreated oysters; the magnitude of changes increased with treatment

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.2 Color Measurements on Surimi and Surimi Products

Task	*Color Effects*	*References*
Order fish mince according to species, processing parameters, and color differences	Color matching of fish mince provide a good basis for assessing practical limits of grading for color	[55]
Washing of fish mince	Resulted in higher *L* and lower *a* values	[56]
Treating of fish mince by H_2O_2	*L* of fish mince increased with increasing levels of H_2O_2. Soaking of fish mince from flaps in H_2O_2 decreased *a* and *b* values	[57,58]
Adding of hydrocolloids to fish mince and observing color changes during frozen storage	During 3 months at –18°C *L* generally decreased slightly, accompanied by increases in *a* and *b*	[59]
Minced sardine flesh washed with different solutions (sodium bicarbonate and water)	*L** of washed mince with 0.5% $NaHCO_3$ increased markedly, while in all treatments *a** decreased and *b** increased in water-washed mince	[60]
Washing of catfish frame mince and influence of storage	*L* values increased whereas *a* and *b* values decreased after washing. During storage at 5, 0, and –20°C *L*, *a*, and *b* remained unchanged	[61]
Influence of refrigerated and frozen storage on surimi color	*L** and *b** taken on Pacific whiting surimi did not change during storage up to 5 d but decreased at day 7. *a** did not change throughout storage. After freezing, surimi showed only slight changes in *L**, *a**, *b** and remained stable during 2 months of frozen storage	[62]
Numbers of washing steps in preparing surimi from channel catfish mince	Significant differences in *L*, *a*, *b* were found between gels prepared with washed and unwashed surimi only after the first wash. There were no additional changes after two or three washes	[63]
Gels prepared from surimi of different fish species with or without protease inhibitors	*L** of cooked gels without inhibitors was lowest for pollock and highest for arrowtooth flounder (AF) surimi. The *a** indicated a more greenish hue. The *b** of AF was highest indicating more yellow hue	[64]
Effect of adding nonmuscle proteins as gelation aid to horse mackerel surimi	The *L** of kamaboko increased within 0.5 h after cooking and then decreased slightly. The *a** decreased and *b** increased gradually. Addition of liquid egg white to kamaboko increased its *L** but reduced *a** and *b**	[65]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.2 (continued) Color Measurements on Surimi and Surimi Products

Task	*Color Effects*	*References*
Addition of several hydrocolloids in different concentrations (0.5%–4.0%) to blue whiting muscle mince	Gel color was virtually unaffected by the presence of different hydrocolloid concentration in the formulation	[66]
Improvement of surimi color of dark-fleshed fish species	Raising water or oil content significantly increased L^* and decreased b^* of the gels. Potato starch decreased b^* but not L^*. In general, adding water, oil, or titanium dioxide was considered as effective to whiten the color of surimi gels	[67]
Color of freeze-dried surimi powder of three marine fish species from Malaysian waters were checked	Highest L was found for threadfin bream, followed by purple-spotted bigeye and lizardfish. Similar results were found for a and b	[68]
Different washing treatments at acidic and alkaline pH areas for kamaboko production from sardine regarding their effect on color of final product	Washing resulted in higher L^* and whiteness index of protein concentrates. Further improvement of both parameters achieved during heating. Lowest a^* reached by alkaline washing at pH 11.5. pH modification also influenced b^* value	[69]
Increase of whiteness of small-scale mud carp gel	Extensive washing increased whiteness. Setting temperature had no effect on color	[70]
Low-salt restructured fish products from Mexican flounder	Using transglutaminase or whey protein concentrate (WPC) decreased L^* while a^* and b^* increased in comparison to control	[71]
Effect of addition of amidated low methoxyl pectin to Mexican flounder	Addition of pectin increased significantly L^* and b^* of the gels whereas a^* increased only slightly	[72]
Effect of quercitin on fish gels fortified with ω-3 fatty acids	L^* is reduced and b^* is almost doubled by addition of quercitin compared to fish gels containing only fish oil	[73]
Comparison of surimi prepared by pH shifting (alkaline, AL; acidic, AC) with conventionally washed surimi (CW)	CW surimi gels exhibited highest whiteness due to higher L^* and lower a^* and b^* values. AC surimi gels were lower in whiteness than AL surimi gels	[74]
Influence of moisture content on surimi color of different fish species	L^* and whiteness increased with higher moisture content, changes in a^* and b^* were not consistent	[75]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.2 (continued) Color Measurements on Surimi and Surimi Products

Task	*Color Effects*	*References*
Extraction and recovery of Atlantic croaker proteins with the pH-shift process	Isolate pastes had higher L^* than surimi pastes, surimi gel had higher L^* than isolate, b^* was highest in acid-aided gel	[76]
Color changes of mince, surimi, and kamaboko from horse mackerel with different washing methods were compared	L^* of mince increased rapidly with ozonized water treatment, but slowly with alkaline solution treatment. Similar changes of L^* in surimi and kamaboko were observed. a^* of mince decreased during washing. Decrease in b^* of surimi and kamaboko was seen. Whiteness of washed mince, surimi, and kamaboko increased with increase in washing time for all three methods and similar patterns were also observed for L^*. L^* and whiteness of surimi were lower than those of washed mince	[77]
Protein recovery from processing by-products via solubilization/precipitation	Gels from proteins recovered from acidic treatments were whiter and less yellow than their basic counterparts	[78]
Surimi containing ω-3 fatty acids from algal oil was prepared by addition of oil-in-water emulsions or bulk oil	All surimi treatments containing algal oil had an increase in L^*, a^*, and b^*. The largest change in color in surimi with algal oil was in b^*	[79]
Influence of various ohmic heating conditions on surimi-starch gels	Surimi-starch gels showed a decrease in L^*, b^*, and whiteness when starch concentration increased. Increase in moisture caused an increase in whiteness. No clear influence on color of applied voltage observed	[80]
Effects of cysteine proteinase inhibitor (CPI) containing fraction from chicken plasma on autolysis inhibition and color of Pacific whiting surimi	No differences in whiteness were observed between samples with and without CPI addition. CPI could be used in surimi seafood without affecting the color of finished products	[81]
Effect of white grape dietary fiber concentrate (WGDF) against hemoglobin-mediated oxidation of washed cod mince, with and without 10% added herring oil. Changes in a^* used as an indicator of lipid oxidation	During ice storage, control samples without Hb did not show changes in a^* both with and without herring oil added. Samples with 2% and 4% added WGDF did not show significant changes in a^* during storage both with and without added herring oil	[82]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.2 (continued) Color Measurements on Surimi and Surimi Products

Task	*Color Effects*	*References*
Influence of processing temperatures (93°C, 85°C, and 75°C) and times (0–120 min) on color of surimi seafood	High processing temperatures and longer processing times deteriorate the color of surimi seafood and are not recommended	[83]
Influence on color of surimi from Alaska pollock (AP), pork leg, and chicken breast (CB) prepared by washing with water two or four times	AP surimi had higher L^* and whiteness than other samples, CB surimi were lower in L^*. a^* and b^* were lower in AP surimi, CB surimi were higher in a^* and b^*	[84]
Inclusion of various levels of a microbial transglutaminase or a carrageenan additive to restructured hake products with or without dietary fiber with regard to its effect on color	Concerning a^* and b^* values, there was a consistent increasing trend with growing carrageenan levels. Higher carrageenan contents made the fish products containing Swelite redder and yellower and inclusion of Fibruline increased a^*	[85]
Feasibility of obtaining fish-restructured products acceptable for consumers determined by mixing striped mullet and Mexican flounder	Gels showed higher darkness and redness in the following order: striped mullet (dark-fleshed), mixture (1:1) of both species, Mexican flounder (white-fleshed)	[86]
Influence on color of using microbial transglutaminase (MTGase) or WPC as binders in preparation low-salted restructured fish products from striped mullet	In low-salt gels, MTGase and WPC had no effect on L^*, WPC increased a^*, MTGase, and WPC increased b^*. The level of salt did not affect the color in restructured products (no changes in L^* observed)	[87]
Color changes of surimi seafood under electron beam (e-beam) and heat	L^* and a^* were not affected by e-beam treatment, L^* and a^* increased when heat treated. Gradual decrease in b^* for e-beam, but increase in b^* in heat-treated samples	[88]

pressure. HP-induced changes in color generally imported a cooked, more voluminous, and juicy appearance to the raw oyster tissue [148]. Further results on the influence of color by treating fish with high pressure are shown in Table 12.6.

12.5 Summary

The overview given here indicates the importance of color measurement in the evaluation of quality and safety in fish processing. One of the advantages is the fact that the measuring technique is not expensive and can therefore be applied on a wide scale.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.3 Color Measurements on Refrigerated Products

Task	*Color Effects*	*References*
Influence of storage condition	RSW-stored ocean perch kept their skin color better than iced fish. *a* values for RSW fish supported by CO_2 were higher. *L* and *b* did not change significantly	[89]
Treatment by antioxidants to preserve skin color during refrigerated and frozen storage	Thornyhead rockfish skin color was generally improved by treatment. After 4 months the control had lost red color. After 8 d of refrigerated storage treated samples maintained more skin redness than control which *a** decreased	[90,91]
Effect of MAP on color of Pacific red snapper during storage at 2°C compared with samples stored in air	*L* decreased over time, *a* was lower after 7 d and no difference in *b* between treatments. After 7 d ΔE higher in MAP and after 21 d ΔE lower in MAP than in air	[92]
Color changes during iced storage early postmortem	Immediately after fish has been caught in demersal fish *L** in fillets increased along body axis from head to tail while in pelagic fish *L** decreased in same direction. *a** appears to decrease in both demersal and pelagic fish fillets while *b** increased in demersal and decreased in pelagic species along body axis from head to tail	[93]
Color changes during iced storage of ray	Slight reduction in *L* while *a* and *b* hardly underwent any variation. On cooked muscle higher *L* and *b* were found that did not change during storage	[94]
Influence of ice type used for storage on color of fish (herring, sardine, and horse mackerel)	Color measurements on the skin of iced stored fish performed on board did not show any significant differences between specimens stored in flake ice and those stored in slurry ice	[95–97]
Influence of CO_2-modified MAP on color of mackerel fillets stored at –2°C for 21 d	*L* and *b* increased significantly at day 14, *a* increased between day 7 and 21. After cooking *L*, *a*, and *b* of CO_2-modified MAP fillet were not significantly different	[98]
Channel catfish fillet strips stored in CO_2 environment	Strips were stored for 4 weeks at 2°C and 8°C under aerobic, 25% CO_2 and 80% CO_2, in CO_2 packed samples *L* increased and *a* decreased	[99]
Influence of tumbling catfish fillets containing 2-methylisoborneol in citric acid solution (0%–2%)	Fish tumbled in 2% acid showed highest *L**, followed by 0.5% acid, water-treated fish and then untreated sample. Fish tumbled with water showed lowest *a** and *b**	[100]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.3 (continued) Color Measurements on Refrigerated Products

Task	*Color Effects*	*References*
Evaluation of color changes of king salmon stored in air packs at 0°C for 22 d	Frame sides had significantly higher a^* and b^* and lower L^* than skin sides. L^* did not change with time. a^* and b^* did not vary with harvest method. a^* at skin side decreased over time	[101]
Evaluation of quality changes of farmed halibut fed by diets only differing in fat content stored in ice for 26 d	L^* and b^* of cutlets increased significantly during first 6 d of storage. Negative a^* decreased between day 4 and 6. No further changes in color after day 6	[102]
Effect of MAP on color changes of gutted farmed sea bass when stored at 3°C for up to 9 d	Six different atmospheres (with increasing CO_2 content) were used for storage. Only a^* and b^* were influenced by storage time. L^* was independent on time	[103]
Comparison of color of sea bass fillets stored in MAP or air	No difference emerged in whiteness among the differently preserved fillets	[104]
Effect of fasting on color of ordinary muscle in full-cycle cultured bluefin tuna during chilled storage	L^*, a^*, and b^* of post-fasting group were lower than for pre-fasting group throughout storage	[105]
Influence of ice storage of sardine and mackerel muscles on redness index (RI) (a^*/b^* ratio)	RI of iced-stored mackeral and sardine muscles decreased when storage time increased. RI of washed mince was lower than that of unwashed mince and decreased during first 6 d of iced storage	[106]
Comparison of color changes in ordinary and dark muscle of yellowtail during iced storage	a^* value in dark muscle was higher than in ordinary muscle at day 0 and decreased during 2 d of ice storage. b^* tended to increase in both muscle types throughout storage whereas L^* changes only slightly. Changes in color tones in both muscles during 4 d of ice storage were different for the different fish species investigated	[107]
Evaluation of color changes in two batches (different areas, sizes, and rearing conditions) of Senegalese sole during 28 d of iced storage	SS-1 lot had significantly higher L^*, a^*, and b^* than the SS-2 lot until rejection point by the sensory panel. L^* and a^* hardly changed throughout storage in both batches whereas b^* for the SS-2 lot increased during storage	[108]
Influence of ice storage of bigeye snappers on color of resulting surimi	Gel whiteness decreased markedly as the storage time increased. Gels prepared from headed and gutted fish had slightly higher whiteness than those produced from whole fish	[109]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.3 (continued) Color Measurements on Refrigerated Products

Task	*Color Effects*	*References*
To study potential skin and fillet color differences at the point of slaughter, during rigor mortis, and after ice storage for 7 d, at a time when the fish are typically available to consumers. Skin color (CIE L^*, a^*, b^*, and related values) was determined by a Minolta Chroma Meter. Roche *Salmo* FanTM Lineal and Roche Color Card values were determined by a computer vision method and a sensory panel	The changes in skin and fillet color of anesthetized and exhausted Atlantic salmon were determined. Perimortem handling stress initially affected several color parameters of skin and fillets. Significant transient fillet color changes also occurred in the pre-rigor phase and during the development of rigor mortis. The color change patterns during storage were different for the two groups of fish. These differences were relatively small and probably could not be spotted by consumers	[26]

Table 12.4 Color Measurements on Frozen Products

Task	*Color Effects*	*References*
Effect of frozen storage at –18°C up to 1 year on color of weakfish fillet	L, a, and b for all product forms did not change significantly between months of harvest and during storage	[110]
Frozen storage (3 and 6 months at –20°C and –80°C) of vacuum-packed fillets of rainbow trout	Increasing L^*, a^*, b^*, and decreasing h^*. Color characteristic from different parts of fillet differed significantly	[111]
Browning progress during frozen storage and after thawing of yellowtail dark muscle	Ratio b^*/a^* was used as indicator to follow the browning progress. When $b^*/a^* > 0.5$, only slight browning. When $b^*/a^* > 0.8$, product becomes not merchantable	[112]
Evaluation of dietary oil source Peruvian fish oil (PO), rapeseed oil (RO), capelin oil (CO), soybean oil (SO) diet, and frozen storage on flesh color of Atlantic salmon	L^* and b^* of fish fed CO diet was lower than the others and a^* of fish fed PO diet was different from those of fish fed RO and SO diets in raw fillet. Important increases in L^*, a^*, b^*, or C^* were observed during frozen storage	[113]
Investigation of seasonal development of color of fillets of Norwegian spring-spawning herring	Fillets were lighter, less red, and yellower at the anterior compared to the posterior end. They tended to become darker and redder with progress of season	[114]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.4 (continued) Color Measurements on Frozen Products

Task	*Color Effects*	*References*
Effect of long-term frozen storage up to 13 months at different temperatures (–10°C, –20°C, –30°C) on color of individually packed fish fillets	Only during storage at –10°C and somewhat lower at –20°C a noticeable increase in L^* was observed. At –30°C L^* did not change. b^* behaved comparable to L^*	[115,116]
Effectiveness of different cryoprotectants in stabilizing color of restructured trout products during frozen storage	After 6 months of frozen storage control and sodium lactate-treated products were lighter and yellower than carbohydrate-treated products. Samples did not differ in a^* after 6 months. After each freeze/thaw cycle control and sodium lactate-treated raw products were lighter than carbohydrate-treated. a^* did not change with increasing number of FT cycles. Carbohydrate-treated products were generally less red and yellow compared to control and lactate-treated products	[117,118]
Preventing color changes in frozen-stored minced muscle of Atlantic mackerel	DE 18 maltodextrin or the combination of sucrose/sorbitol slowed down color changes. b and a were respectively lower and higher in treated samples than in control. Only slight differences between samples were found in L	[119]
Influence on whiteness (WS) of natural actomyosin (NAM)	WS of NAM extracted from frozen fillets and was less than that of NAM extracted from fresh fish. When whole frozen fish was used for NAM extraction WS was less compared with NAM from frozen fillet. WS decreased in the presence of aldehydes	[120]
Impact of freezing temperature (–10°C, –25°C, –40°C, –55°C, or –70°C) on color of farmed Atlantic cod fillet	Regression analysis showed curvilinear relationship between freezing temperature and L^*. Fillets frozen at –10°C had higher L^* than those frozen at –70°C. L^* were similar for fillets frozen at –25°C to –55°C	[121]
Fading phenomenon of farmed steelhead fillet during frozen storage	The increases in expressible fluid correlated positively with fading (L^*) and negatively with a^*	[122]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.5 Color Measurements on Heat-Treated Products

Task	*Color Effects*	*References*
Influence of species and formulation on color of AP, catfish, and redfish during thermal processing	*L* increased for catfish but decreased for redfish and AP after thermal processing, *a* and *b* increased in general during canning, formulation of canned products had no effect on color	[124]
Effects of tripolyphosphate dips on color of thermally processed mullet	Only *b* was significantly influenced by treatment, also when fresh and frozen fish in using for canning were compared	[125]
Discoloration in thermally processed blue crab meat	Blue crab meat became darker with increasing heating process. Meat at bottom of a can was darker than that on top	[126]
Effect of heating of Pacific chum salmon in water (60°C–100°C) for 0–40 min	Increase in processing temperature or time increased *L**, but decreased *a** and *b** of muscle	[127]
Effect of cooking of aquacultured fish fillets (pacu, rainbow trout, hybrid striped bass, catfish, and tilapia)	Cooking increased *L* and decreased *a* and *b*. Strongest change in *L* observed in catfish and least change in hybrid striped bass	[128]
Effect of baking and cold smoking on color of cultured and wild salmon	Baking and smoking caused *a** to decrease, while *L** increased. No color differences between wild and farmed salmon. Color of raw, baked, and smoked rainbow trout flesh was related to carotenoid concentration of raw flesh	[129,130]
Relation of color and color stability of smoked fillets during chill storage to duration of frozen storage prior to smoking of fillets	Smoked fillets from fish fed lower level of astaxanthin had significantly higher *L*, lower *a* and *b* compared to smoked products from fish fed higher level. Smoked products from fish fed high fat level had higher *L* and lower *a* and *b* than smoked fillets from fish fed diet with the lowest fat level. Only small changes in color during chill storage	[131]
Color changes in smoked rainbow trout fed diet supplemented with canthaxanthin in combination with different lipid levels and the effect of different packaging conditions	Smoke-curing lead to a decrease of *L** and an increase of *h** more marked in fish fed the diet with high lipid level. Use of MAP for the packaging of fillets lead to maintain the color of the flesh in comparison with packaging under vacuum or under air	[132]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.5 (continued) Color Measurements on Heat-Treated Products

Task	*Color Effects*	*References*
Investigation of effects of salting (injection salting vs. dry salting), smoking temperature (20°C vs. 30°C), and storage (chilled storage vs. no storage) on surface color of cold smoked salmon fillets	Higher increase in b^* and C^* and higher h^* and ΔE^* of dry-salted than injection-salted fillets. No influence on L^* and a^* by salting method. Drop in a^* was higher after smoking fillets at 20°C than at 30°C, ΔE^* was higher when fillets were smoked at 30°C than at 20°C	[133]
Comparison of color of sliced salmon sampled in a French hypermarket from fish originally grown in Norway, Scotland, and Ireland	There was a significant effect of country of origin on color, with the Irish having higher values for a^*, b^*, C^*, and h^* than the Norwegian with the Scottish in-between	[134,135]
Effects of cold-smoking temperature (range 21.5°C–29.9°C) and dietary oil sources (pure Peruvian fish oil (FO) or pure SO supplements) on color characteristics	Only b^* values exhibited correlations with temperature. Dietary oil source only had significant effects on a^* and C^* during storage. Salmon fed diets with FO were slightly redder than salmon fed SO. FO-group had C^* values higher than SO-group	[136]
Effects of tripolyphosphate (STPP) in brine on smoke adsorption and color of cold smoked mullet	L, reflecting smoke adsorption, was lightest for control fillets, followed by 5% salt treatment, and darkest for 5% and 10% STPP both with 5% salt	[137]
Comparison of steam blanching, water blanching, and MW-heating applied to desalted cod	Thermally treated cod was lighter and little yellower. Heat induced changes in cod were a little smaller than in MW-heated cod	[138]
Color analysis of skinless catfish fillets from steam-treated catfish and control	No differences in L, a, b, and whiteness were found between steam-treated and control fillets	[139]
Effects of sous vide cooking on color of fish/sauce packs	Sous vide cooking caused a loss of L, a, and b. Sauce color lightened as indicated by a rise in L/b values	[140]
Influence of irradiation on color of rainbow trout muscle	Significant difference in L^* at the time before and after exposure. a^* was identical and b^* decreased	[141]
Assessment of influence of heating on rainbow trout muscle color by heated fish cutlets at temperatures in the range 30°C–70°C	L^* most influenced by heating increased linearly up to 60°C without further changes. a^* did not change markedly whereas b^* slightly increased at higher temperatures	[142]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.5 (continued) Color Measurements on Heat-Treated Products

Task	*Color Effects*	*References*
Variability in color of smoked salmon samples	Values obtained on 114 smoked salmon with L^* (45.4–61.8), a^* (13.4–34.2), and b^* (16.9–33.7) reflect their variability in color	[143]
Evaluation of kinetics of reactions leading to changes in salmon color during thermal processing	When heating, muscle color is characterized by rapid whitening followed by slow browning. Whitening occurred within the first 10 min with L^* increased to a maximum and a^* and b^* decreased to a minimum. During browning, changes of L^*, b^*, and ΔE^* followed a zero-order reaction	[144]
Effect of fat content and fillet shape on color of smoked Atlantic salmon	Smoked salmon had lower L^* and a^* and higher b^* compared with raw salmon. Ice-stored salmon displayed higher change due to smoking in L^* and lower change of a^* and b^* with increasing fat content. The change in L^*, a^*, and b^* of frozen stored salmon showed no correlation with raw material characteristics. Changes in color from raw to smoked products are affected by variations in fat content only when fresh material is used	[145]
Influence on color of cold smoked Atlantic salmon by freezing the raw fish before smoking and by freezing the finished product after smoking	L^*, a^*, and b^* increased significantly due to freezing before and after smoking. Freezing before smoking had a significant effect on L^*: fish frozen whole and fish frozen as fillets had higher L^* than freshly smoked fillets. Freezing before smoking, either as whole fish or as fillets, also increased a^* and b^*. Freezing of fillets after smoking increased average a^* and b^* values in fillets that were either stored fresh or frozen after smoking, respectively. Increases in a^* and b^* were much larger than increase in L^*	[146]
Color changes in skinless mahimahi fillet portions either treated with filtered smoke (FS) or left untreated for 24 h, followed by either aerobic storage at 4°C for 8 d or freezing for 30 d (–25°C) followed by thawing and aerobic storage at 4°C for 8 d	Treating mahimahi fillets with FS increased a^* in muscle and stabilized it during frozen storage. Redness did decay rapidly on cold storage for both defrosted and fresh filtered-smoke-treated products, and reached initial (pre-smoking) redness levels in 2 d	[147]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.6 Color Measurements on Fish Treated by High Pressure

Task	*Color Effects*	*References*
Pressure-treatment of pelagic and demersal species from different fishing grounds using same conditions	Color changes measured on demersal fishes caused by pressure treatment resulted in marked increase of L^* and in decreases of both a^* and b^*. High-pressure treatments (higher than 150–200 MPa, 5 min) resulted in a cooked appearance of pollock, cod, tuna, mackerel, salmon trout, carp, plaice, and anglerfish. Only octopus retained a raw appearance till 400–800 MPa	[149,150]
High pressure (100–300 MPa) applied (for 0–30 min) to fresh seafood to control enzyme-related texture	L and b increased progressively with amount of pressure applied and duration of pressure application while a was reduced. ΔE indicated no color difference between sample treated up to 200 MPa for 10 min	[151]
Changes in color of turbot fillets during frozen storage at –20°C after pressure shift freezing (PSF) and air blast freezing (ABF)	PSF resulted in overall increase in L^* and b^* and decrease in a^*. Frozen storage did not particularly modify color parameters of PSF fillets. ABF did not give a cooked aspect after thawing to the turbot fillets. During the storage of ABF fillets, b^* increased significantly	[152]
Influence of high-pressure-assisted thawing (PAT) on color of fillets from redfish, cod, rainbow trout, whiting, haddock, and salmon	In raw fillets, color changes (high ΔE^*) were mainly caused by a strong increase in L^*. Smaller changes were monitored for a^* (decrease) and b^* (increase). After heat treatment, the influence of high pressure on color was much smaller. ΔE^* between cooked fillets previously thawed either by high-pressure treatment or conventionally, varied from negligible to significant	[153]
Color changes in carp muscle exposed to high pressures of 50–500 MPa/10 min	Carp muscles lost their transparency, L increased parallel with an increase of pressurization at room temperature	[154]
Effect of high-pressure treatment (up to 500 MPa, 5 min) on color of sea bass fillets after 0, 7, and 14 d of refrigerated storage	Nonpressurized fillets showed an increase in L^* for refrigerated storage time of 7 d, followed by decrease in L^* after 14 d of storage. a^* and b^* remained constant during storage. Regardless of pressure level, application of pressure on fillet increased L^*	[155]
High pressure to obtain cod sausage with added chitosan	After pressure treatment L^* increased markedly, whereas b^* decreased slightly	[156]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.6 (continued) Color Measurements on Fish Treated by High Pressure

Task	*Color Effects*	*References*
Effect of high-pressure treatments at 400 and 600 MPa (1 and 5 min) on color of heat-induced fish gels obtained from arrowtooth flounder fish paste	Thermal treatments of pressure-treated and control samples were assigned to kamaboko (90°C), setting (40°C/90°C) and modori (60°C/90°C). L^* ranged from 76.6 to 81.7, a^* were from −1.37 to −0.69 and b^* varied from 6.0 to 10.9. Modori samples had lowest L^*	[157]
Comparison of AP and Pacific whiting surimi gels containing potato starch and/or egg white (400 and 650 MPa for 10 min at 20°C) with heat-induced gels (90°C, 40 min)	Pressure treatment improved whiteness (WS) of surimi gels as compared with heat-treated surimi gels, whereas additives did not. At 400 MPa WS was 10% higher than heated gels. At 650 MPa WS increased 8%	[158]
Effect on color of minced albacore muscle treated with high hydrostatic pressure at 275 and 310 MPa for 2–6 min	L^* increased with pressure giving a lighter product, a^* decreased and b^* increased giving a light yellow/grayish hue, cooked appearance product	[159]
Effect of combined application of high-pressure treatment and modified atmospheres on color of fresh Atlantic salmon	L^* of salmon increased with increasing intensity and time of pressurization. High-pressure treatment (150 MPa, 60 min or 200 MPa, 10 min) resulted in an opaque product ($L^* > 70$). A product with $L^* > 70$ or $a^* < 13$ is unacceptable	[160]
Changes in whiteness of tilapia gels obtained by combined hydrostatic pressure (200 MPa) and setting (50°C) treatments	The whiteness, which is related to the degree of protein denaturation, was highest in the gel formed by cooking	[161]
Effects of PSF and/or PAT on color of sea bass muscle were evaluated and compared with conventional (air-blast) frozen (AF) and thawed (AT) samples	L^* did not change when the muscle was treated by AF/AT, but showed a very important increase in the high-pressure-treated systems (AF/PAT, PSF/AT, and PSF/PAT), being still larger in the case of the PSF/PAT. b^* increased in all high-pressure treated systems. a^* did not present modifications due to application of high pressure. After cooking, all systems showed similar appearance	[162]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 12.6 (continued) Color Measurements on Fish Treated by High Pressure

Task	*Color Effects*	*References*
Investigation of the effect of high-pressure treatment on color of rainbow trout and mahimahi during cold storage for 6 d	*L** for rainbow trout increased as pressure increased and did not change after 3 d storage. *L** increased after 6 d storage compared to the other 2 d. *a** decreased after pressurization. For mahimahi *L** increased slightly with increasing pressure, during storage *L** differed slightly. As pressure and storage time increased *a** decreased. *b** increased over the control for all pressures tested	[163]
Effect of different levels of pressure treatment on the color of vacuum-packed cold-smoked dolphinfish (*Coryphaena hippurus*) and on the subsequent chilled storage at 5°C of the final product	*L** was lower in fillets than in slices and increased with pressure, especially in slices. *a** and *b** in fillets increased with pressure. During chilled storage for 70 d, *L** was quite stable in pressure-treated and untreated smoked slices. *L** in pressurized sample was higher than in untreated batch. During chilled storage *a** increased in both batches. Pressurization brought about a slight increase in *b** and values held relatively steady during chilled storage. *b** increased in the unpressurized batch during storage	[164]

References

1. MacDougall, D.B., *Colour in Food: Improving Quality*, Woodhead Publishing, Cambridge, U.K., 2002.
2. Downham, A. and Collins, P., Colouring our foods in the last and next millennium, *Int. J. Food Sci. Technol.*, 35, 5, 2000.
3. Lawless, H.T. and Heymann, H., *Sensory Evaluation of Food. Principles and Practices*, Chapman & Hall, New York, 1998, p. 379.
4. Clydesdale, F.M., Color perception and food quality, *J. Food Qual.*, 14, 61, 1991.
5. Love, R.M., *The Food Fishes. Their Intrinsic Variation and Practical Implications*, Farrand Press, London, U.K., 1988.
6. Baardseth, P. et al., A comparison of CIE (1976) L*a*b* values obtained from two different instruments on several food commodities, *J. Food Sci.*, 53, 1737, 1988.
7. Stien, L.H. et al., Instrumental colour analysis of Atlantic salmon (*Salmo salar* L.) muscle, in: *Seafood Research from Fish to Dish. Quality, Safety and Processing of Wild and Farmed Fish.* Luten, J.B. et al., Eds., Wageningen Academic Publishers, Wageningen, the Netherlands, 2006, p. 525.
8. Fullerton, A. and Keiding, J., A comparison between a tristimulus colorimeter (Minolta Chroma-Meter CR-200) and two spectrophotometers (Minolta Spectrophotometer CM-508i and CM-2002). Quantification of UV-B induced erythema in a hairless guinea pig model, *Skin Res. Technol.*, 3, 237, 1997.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

9. Zheng, C., Sun, D.W., and Zheng, L., Recent developments and applications of image features for food quality evaluation and inspection—A review, *Trends Food Sci. Technol*., 17, 642, 2006.
10. Stien, L.H. et al., Automated image analysis as a tool to quantify the colour and composition of rainbow trout (*Oncorhynchus mykiss* W.) cutlets, *Aquaculture*, 261, 695, 2006.
11. León, K. et al., Color measurement in *L*a*b** units from RGB digital images, *Food Res. Int*., 39, 1084, 2006.
12. Yam, K.L. and Papadakis, S.E., A simple digital imaging method for measuring and analyzing color of food surfaces, *J. Food Eng*., 61, 137, 2004.
13. Louka, N. et al., A novel colorimetry analysis used to compare different drying fish processes, *Food Control*, 15, 327, 2004.
14. Korel, F., Luzuriaga, D.A., and Balaban, M.Ö., Objective quality assessment of raw tilapia (*Oreochromis niloticus*) fillets using electronic nose and machine vision, *J. Food Sci*., 66, 1018, 2001.
15. Olafsdottir, G. et al., Multisensor for fish quality determination, *Trends Food Sci. Technol*., 15, 86, 2004.
16. Di Natale, C., Data fusion in MUSTEC: Towards the definition of an Artificial Quality Index, in: *Quality of Fish from Catch to Consumer: Labelling, Monitoring & Traceability*, Luten, J.B., Oehlenschläger, J., and Olafsdottir, G., Eds., Wageningen Academic Publishers, Wageningen, the Netherlands, 2003, p. 273.
17. Balaban, M.O., Kristinsson, H.G., and Otwell, W.S. Evaluation of color parameters in a machine vision analysis of carbon monoxide-treated fish. Part I: Fresh tuna, *J. Aquat. Food Prod. Technol*., 14, 5, 2005.
18. Pavlidis, M., Papandroulakis, N., and Divanach, P., A method for the comparison of chromaticity parameters in fish skin: Preliminary results for coloration pattern of red skin Sparidae, *Aquaculture*, 258, 211, 2006.
19. Pearson, A.M. and Dutson, T.R., *Quality Attributes and Their Measurement in Meat, Poultry and Fish Products*, Blackie Academic & Professionals, Glasgow, U.K., 1994.
20. Hutchings, J.B., *Food Color and Appearance*, Aspen Publishers, Gaithersburg, MD, 1999.
21. Hutchings, J.B., *Food Colour and Appearance*, Blackie Academic & Professionals, Glasgow, U.K., 1994.
22. Hutchings, J.B., *Expectations and the Food Industry: The Impact of Color and Appearance*, Kluwer Academic/Plenum Publishers, Dordrecht, the Netherlands, 2003.
23. Kress-Rogers, E., *Instrumentation and Sensors for the Food Industry*, Butterworth Heinemann, Oxford, U.K., 1993.
24. Kress-Rogers, E. and Brimelow, C.J.B., *Instrumentation and Sensors for the Food Industry*, 2nd edn., Woodhead Publishing, Cambridge, U.K., 2001.
25. Jakobsen, M. and Bertelsen, G., Modelling colour stability in meat, in *Colour in Food: Improving Quality*, MacDougall, D.B., Ed., Woodhead Publishing., Cambridge, U.K., 2002, p. 233.
26. Erikson, U. and Misimi, E., Atlantic salmon skin and fillet color changes effected by perimortem handling stress, rigor mortis, and ice storage, *J. Food Sci*., 73, C50, 2008.
27. Reid, R.A. et al., Structural and chemical changes in the muscle of chum salmon (*Oncorhynchus keta*) during spawning migration, *Food Res. Int*., 26, 1, 1993.
28. Choubert, G., Blanc, J.-M., and Courvalin, C., Muscle carotenoid content and colour of farmed rainbow trout fed astaxanthin or canthaxanthin as affected by coking and smoke-curing procedures, *Int. J. Food Sci. Technol*., 27, 277, 1992.
29. Hatlen, B., Jobling, M., and Bjerkeng, B., Relationships between carotenoid concentration and colour of fillets of Arctic charr, *Salvelinus alpinus* (L.), fed astaxanthin, *Aquacult. Res*., 29, 191, 1998.
30. Ginés, R. et al., Effects of rearing temperature and strain on sensory characteristics, texture, colour and fat of Arctic charr (*Salvelinus alpinus*), *Food Qual. Pref*., 15, 177, 2004.
31. Shahidi, F., Synowiecki, J., and Penney, R.W., Pigmentation of Arctic char (*Salvelinus alpinus*) by dietary carotenoids, *J. Aquat. Food Prod. Technol*., 2, 99, 1993.
32. Jankowska, B. et al., A comparison of selected quality features of the tissue and slaughter yield of wild and cultivated pikeperch *Sander lucioperca* (L.), *Eur. Food Res. Technol*., 217, 401, 2003.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

33. Choubert, G., Blanc, J.-M., and Valle, F., Colour measurement, using the CIELCH colour space, of muscle of rainbow trout, *Oncorhynchus mykiss* (Walbaum), fed astaxanthin: Effects of family, ploidy, sex, and location of reading, *Aquacult. Res*., 28, 15, 1997.
34. Bjerkeng, B. et al., Quality parameters of the flesh of Atlantic salmon (*Salmo salar*) as affected by dietary fat content and full-fat soybean meal as a partial substitute for fish meal in the diet, *Aquaculture*, 157, 297, 1997.
35. Morzel, M., Sohier, D., and van de Vis, H., Evaluation of slaughtering methods for turbot with respect to animal welfare and flesh quality, *J. Sci. Food Agric*., 83, 19, 2003.
36. Roth, B., Slinde, E., and Arildsen, J., Pre or post mortem muscle activity in Atlantic salmon (*Salmo salar*). The effect on rigor mortis and the physical properties of flesh, *Aquaculture*, 257, 504, 2006.
37. Kiessling, A. et al., Texture, gaping and colour of fresh and frozen Atlantic salmon flesh as affected by pre-slaughter iso-eugenol or CO_2 anaesthesia, *Aquaculture*, 236, 645, 2004.
38. Bjørnevik, M. et al., Temporal variation in muscle fibre area, gaping, texture, colour and collagen in triploid and diploid Atlantic salmon (*Salmo salar* L), *J. Sci. Food Agric*., 84, 530, 2004.
39. Segato, S. et al., Effect of triploidy on quality traits of shi drum (*Umbrina cirrosa* L.) until the second rearing year, *Aquacult. Res*., 38, 59, 2007.
40. Skjervold, P.O. et al., Properties of salmon flesh from different locations on pre- and post rigor fillets, *Aquaculture*, 201, 91, 2001.
41. Kristoffersen, S. et al., Effects of pre-rigor filleting on quality aspects of Atlantic cod (*Gadus morhua* L.), *Aquacult. Res*., 37, 1556, 2006.
42. Ginés, R. et al., The effects of long-day photoperiod on growth, body composition and skin colour in immature gilthead sea bream (*Sparus aurata* L.), *Aquacult. Res*., 35, 1207, 2004.
43. Kalinowski, C.T. et al., Effect of different carotenoid sources and their dietary levels on red porgy (*Pagrus pagrus*) growth and skin colour, *Aquaculture*, 244, 223, 2005.
44. Jankowska, B. et al., Slaughter value and flesh characteristics of European catfish (*Silurus glanis*) fed natural and formulated feed under different rearing conditions, *Eur. Food Res. Technol*., 224, 453, 2007.
45. Hallier, A. et al., Influence of farming conditions on colour and texture of European catfish (*Silurus glanis*) flesh, *J. Sci. Food Agric*., 87, 814, 2007.
46. González, S. et al., Composition of farmed and wild yellow perch (*Perca flavescens*), *J. Food Comp. Anal*., 19, 720, 2006.
47. Arredondo-Figueroa, J.L. et al., Color of raw, frozen, and smoked fillets of rainbow trout (*Oncorhynchus mykiss*) fed diets supplemented with astaxanthin and saponified red chilli (*Capsicum annuum*) extracts, *J. Aquat. Food Prod. Technol*., 16, 35, 2007.
48. Doolan, B.J. et al., Effect of cage colour and light environment on the skin colour of Australian snapper *Pagrus auratus* (Bloch & Schneider, 1801), *Aquacult. Res*., 38, 1395, 2007.
49. Suontama, J. et al., Protein from Northern krill (*Thysanoessa inermis*), Antarctic krill (*Euphausia superba*) and the Arctic amphipod (*Themisto libellula*) can partially replace fish meal in diets to Atlantic salmon (*Salmo salar*) without affecting product quality, *Aquacult. Nutr*., 13, 50, 2007.
50. Jankowska, B. et al., Slaughter yield, proximate composition, and flesh colour of cultivated and wild perch (*Perca fluviatilis* L.), *Czech J. Anim. Sci*., 52, 260, 2007.
51. Osterlie, M. et al., Influence of added astaxanthin level and color on flavor of pastes of rainbow trout, *J. Aquat. Food Prod. Technol*., 10, 65, 2001.
52. Lanier, T.C. and Lee, C.M., *Surimi Technology*, Marcel Dekker, New York, 1992.
53. Park, J.W., *Surimi and Surimi Seafood*, Marcel Dekker, New York, 2000.
54. Park, J.W., *Surimi and Surimi Seafood*, 2nd edn., Marcel Dekker, New York, 2005.
55. Young, K.W. and Whittle, K.J., Colour measurement of fish minces using Hunter *L*, *a*, *b* values, *J. Sci. Food Agric*., 36, 383, 1985.
56. Eid, N., Dashti, B., and Sawaya, W., Sub-tropical fish by-catch for surimi processing, *Lebensm.-Wiss. u.-Technol*., 24, 103, 1991.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

57. Brown, P., Rasco, B.A., and Borhan, M., Color removal from the dark muscle of Alaskan pollock (*Theragra chalcogramma*) fillets and minces using peroxide, *J. Aquat. Food Prod. Technol.*, 2, 125, 1993.
58. Himonides, A.T., Taylor, K.D.A., and Knowles, M.J., The improved whitening of cod and haddock flaps using hydrogen peroxide, *J. Sci. Food Agric.*, 79, 845, 1999.
59. da Ponte, D.J.B., Roozen, J.P., and Pilnik, W., Effects of additions on the stability of frozen stored minced fillets of whiting. II. Various anionic and neutral hydrocolloids, *J. Food Qual.*, 8, 183, 1985.
60. Barrero, M. and Bello, R.E., Characterisation of sardine minced flesh (*Sardinella aurita*) washed with different solutions, *J. Aquat. Food Prod. Technol.*, 9, 105, 2000.
61. Suvanich, V., Marshall, D.L., and Jahncke, M.L., Microbiological and color quality changes of channel catfish frame mince during chilled and frozen storage, *J. Food Sci.*, 65, 151, 2000.
62. Pipatsattayanuwong, S., Park, J.W., and Morrissey, M.T., Functional properties and shelf life of fresh surimi from Pacific whiting, *J. Food Sci.*, 60, 1241, 1995.
63. Kim, J.M. et al., Surimi from fillet frames of channel catfish, *J. Food Sci.*, 61, 428, 1996.
64. Reppond, K.D., Wasson, D.H., and Babbitt, J.K., Properties of gels produced from blends of arrowtooth flounder and Alaska pollock surimi, *J. Aquat. Food Prod. Technol.*, 2, 83, 1993.
65. Chen, H.H., Effect of non-muscle protein on the thermogelation of horse mackerel surimi and the resultant cooking tolerance of kamaboko, *Fisheries Sci.*, 66, 783, 2000.
66. Pérez-Mateos, M. and Montero, P., Contribution of hydrocolloids to gelling properties of blue whiting muscle, *Eur. Food Res. Technol.*, 210, 383, 2000.
67. Hsu, C.-K. and Chiang, B.-H., Effects of water, oil, starch, calcium carbonate and titanium dioxide on the colour and texture of threadfin and hairtail surimi gels. *Int. J. Food Sci. Technol.*, 37, 387, 2002.
68. Huda, N., Abdullah, A., and Babji, A.S., Functional properties of surimi powder from three Malaysian marine fish. *Int. J. Food Sci. Technol.*, 36, 401, 2001.
69. Karayannakidis, P.D. et al., The effect of initial wash at acidic and alkaline pHs on the properties of protein concentrate (kamaboko) products from sardine (*Sardina pilchardus*) samples, *J. Food Eng.*, 78, 775, 2007.
70. Yongsawatdigul, J., Piyadhammaviboon, P., and Singchan, K., Gel-forming ability of small scale mud carp (*Cirrhiana microlepis*) unwashed and washed mince as related to endogenous proteinases and transglutaminase activities, *Eur. Food Res. Technol.*, 223, 769, 2006.
71. Ramírez, J.A. et al., Production of low-salt restructured fish products from Mexican flounder (*Cyclopsetta chittendeni*) using microbial transglutaminase or whey protein concentrate as binders, *Eur. Food Res. Technol.*, 223, 341, 2006.
72. Uresti, R.M. et al., Effect of amidated low methoxyl pectin on the mechanical properties and colour attributes of fish mince, *Food Technol. Biotechnol.*, 41, 131, 2003.
73. Pérez-Mateos, M. et al., Quercetin properties as a functional ingredient in omega-3 enriched fish gels fed to rats, *J. Sci. Food Agric.*, 85, 1651 2005.
74. Pérez-Mateos, M. and Lanier, T.C., Comparison of Atlantic menhaden gels from surimi processed by acid or alkaline solubilization, *Food Chem.*, 101, 1223, 2007.
75. Reppond, K.D. and Babbitt, J.K., Gel properties of surimi from various fish species as affected by moisture content, *J. Food Sci.*, 62, 33, 1997.
76. Kristinsson, H.G. and Liang, Y., Effect of pH-shift processing and surimi processing on Atlantic croaker (*Micropogonias undulates*) muscle proteins, *J. Food Sci.*, 71, C304, 2006.
77. Chai, P.P. and Park, J.W., Physical properties of fish proteins cooked with starches or protein additives under ohmic heating, *J. Food Qual.*, 30, 783, 2007.
78. Chen, Y.-C. and Jaczynski, J., Protein recovery from rainbow trout (*Oncorhynchus mykiss*) processing byproducts via isoelectric solubilization/precipitation and its gelation properties as affected by functional additives, *J. Agric. Food Chem.*, 55, 9079, 2007.
79. Park, Y. et al., Incorporation and stabilization of omega-3 fatty acids in surimi made from cod, *Gadus morhua*, *J. Agric. Food Chem.*, 52, 597, 2004.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

80. Pongviratchai, P. and Park, J.W., Electrical conductivity and physical properties of surimi-potato starch under ohmic heating, *J. Food Sci.*, 72, E503, 2007.
81. Rawdkuen, S. et al., Effect of cysteine proteinase inhibitor containing fraction from chicken plasma on autolysis and gelation of Pacific whiting surimi, *Food Hydrocoll.*, 21, 1209, 2007.
82. Sanchez-Alonso, I. et al., Inhibition of hemoglobin-mediated oxidation of regular and lipid-fortified washed cod mince by a white grape dietary fiber, *J. Agric. Food Chem.*, 55, 5299, 2007.
83. Shie, J.S. and Park, J.W., Physical characteristics of surimi seafood as affected by thermal processing conditions, *J. Food Sci.*, 64, 287, 1999.
84. Jin, S.-K. et al., Effect of muscle type and washing times on physico-chemical characteristics and qualities of surimi, *J. Food Eng.*, 81, 618, 2007.
85. Cardoso, C., Mendes, R., and Nunes, M.L., Effect of transglutaminase and carrageenan on restructured fish products containing dietary fibres, *Int. J. Food Sci. Technol.*, 42, 1257, 2007.
86. Ramírez, J.A. et al., Low-salt restructured fish products using low-value fish species from the gulf of Mexico, *Int. J. Food Sci. Technol.*, 42, 1039, 2007.
87. Ramírez, J.A. et al., Low-salt restructured products from striped mullet (*Mugil cephalus*) using microbial transglutaminase or whey protein concentrate as additives, *Food Chem.*, 102, 243, 2007.
88. Jaczynski, J. and Park, J.W., Physicochemical properties of surimi seafood as affected by electron beam and heat, *J. Food Sci.*, 68, 1626, 2003.
89. Longard, A.A. and Regier, L.W., Color and some composition changes in ocean perch (*Sebastes marinus*) held in refrigerated sea water with and without carbon dioxide, *J. Fish. Res. Board. Can.*, 31, 456, 1974.
90. Wasson, D.H., Reppond, K.D., and Kandianis, T.M., Antioxidants to preserve rockfish color, *J. Food Sci.*, 56, 1564, 1991.
91. Li, S.J. et al., Color stability and lipid oxidation of rockfish as affected by antioxidant from shrimp shell waste, *J. Food Sci.*, 63, 438, 1998.
92. Gerdes, D.L. and Santos Valdez, C., Modified atmosphere packaging of commercial Pacific red snapper (*Sebastes entomelas*, *Sebastes flavidus*, or *Sebastes goodei*), *Lebensm.-Wiss. u.-Technol.*, 24, 256, 1991.
93. Schubring, R., Determination of fish freshness by instrumental colour measurement, *Fleischwirtschaft Int.*, 2, 26, 1999.
94. Pastoriza, L. and Sampedro, G., Influence of ice storage on ray (*Raja clavata*) wing muscle, *J. Sci. Food Agric.*, 64, 9, 1994.
95. Schubring, R. and Meyer, C., Ice storage of fish, new aspects: Comparison between flake ice and stream ice—Part I: Sardine (*Sardina pilchardus*), *Dtsch. Lebensm.-Rundsch.*, 102, 405, 2006.
96. Schubring, R. and Meyer, C., Iced storage of fish, new aspects: Comparison between flake ice and stream ice—Part II: Horse mackerel (*Trachurus trachurus*), *Dtsch. Lebensm.-Rundsch.*, 102, 508, 2006.
97. Schubring, R. and Meyer, C., Iced storage, new aspects: Comparison between flake ice and stream ice—Part III: Herring (*Clupea harengus*), *Dtsch. Lebensm.-Rundsch.*, 103, 203, 2007.
98. Hong, L.C. et al., Quality of Atlantic mackerel (*Scomber scombrus* L.) fillets during modified atmosphere storage, *J. Food Sci.*, 61, 646, 1996.
99. Silva, J.L. and White, T.D., Bacteriological and colour changes in modified atmosphere-packaged channel catfish, *J. Food Protect.*, 57, 715, 1994.
100. Forrester, P.N. et al., Treatment of catfish fillets with citric acid causes reduction of 2-methylisoborneol, but not musty flavour, *J. Food Sci.*, 67, 2615, 2002.
101. Fletcher, G.C. et al., Spoilage of rested harvested King salmon (*Oncorhynchus tshawytscha*), *J. Food Sci.*, 68, 2810, 2003.
102. Guillerm-Regost, C. et al., Quality characterization of farmed Atlantic halibut during ice storage, *J. Food Sci.*, 71, S83, 2006.
103. Torrieri, E. et al., Influence of modified atmosphere packaging on the chilled shelf life of gutted farmed bass (*Dicentrarchus labrax*), *J. Food Eng.*, 77, 1078, 2006.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

104. Poli, B.M. et al., Sensory, physical, chemical and microbiological changes in European sea bass (*Dicentrarchus labrax*) fillets packed under modified atmosphere/air or prepared from whole fish stored in ice, *Int. J. Food Sci. Technol*., 41, 444, 2006.
105. Nakamura, Y.-N. et al., Effect of fasting on physical/chemical properties of ordinary muscles in full-cycle cultured Pacific bluefin tuna *Thunnus orientalis* during chilled storage, *Fisheries Sci*., 72, 1079, 2006.
106. Chaijan, M. et al., Changes of pigments and color in sardine (*Sardinella gibbosa*) and mackerel (*Rastrelliger kanagurta*) muscle during iced storage, *Food Chem*., 93, 607, 2005.
107. Sohn, J.-H. et al., Lipid oxidations in ordinary and dark muscles of fish: Influences on rancid off-odor development and color darkening of yellowtail flesh during ice storage, *J. Food Sci*., 70, S490, 2005.
108. Tejada, M. and De las Heras, C., Sensory changes in farmed Senegalese sole (*Solea senegalensis*) during ice storage, *Food Sci. Technol. Int*., 13, 117, 2007.
109. Benjakul, S. et al., Gel-forming properties of surimi produced from bigeye snapper, *Priacanthus tayenus* and *P. macracanthus*, stored in ice, *J. Sci. Food Agric*., 82, 1442, 2002.
110. Waters, M.E., Chemical composition and frozen storage stability of weakfish, *Cynoscion regalis*, *Mar. Fish. Rev*., 45, 27, 1983.
111. No, H.K. and Storebakken, T., Color stability of rainbow trout fillets during frozen storage, *J. Food Sci*., 56, 969, 1991.
112. Hiraoka, Y. et al., Preventive method of color deterioration of yellowtail dark muscle during frozen storage and post thawing, *Fisheries Sci*., 70, 1130, 2004.
113. Regost, C., Jakobsen, J.V., and Rørå, A.M.B., Flesh quality of raw and smoked fillets of Atlantic salmon as influenced by dietary oil sources and frozen storage, *Food Res. Int*., 37, 259, 2004.
114. Hamre, K., Lie, O., and Sandnes, K., Development of lipid oxidation and flesh colour in frozen stored fillets of Norwegian spring-spawning herring (*Clupea harengus* L.). Effects of treatment with ascorbic acid, *Food Chem*., 82, 447, 2003.
115. Schubring, R., Instrumental colour, texture, water holding and DSC measurements on frozen cod fillets (*Gadus morhua*) during long term storage at different temperatures, *Dtsch. Lebensm.-Rundsch*., 100, 247, 2004.
116. Schubring, R., Changes in texture, water holding capacity, colour, and thermal stability of frozen cod (*Gadus morhua*) fillets: Effect of frozen storage temperature, *Dtsch. Lebensm.-Rundsch*., 101, 484, 2005.
117. Jittinandana, S., Kenney, P.B., and Slider, S.D., Cryoprotectants affect physical properties of restructured trout during frozen storage, *J. Food Sci*., 70, C35, 2005.
118. Jittinandana, S., Kenney, P.B., and Slider, S.D., Cryoprotectants preserve quality of restructured trout products following freeze thaw cycling, *J. Muscle Foods*, 16, 354, 2005.
119. Rodríguez-Herrera, J.J. et al., Possible role for cryostabilizers in preventing protein and lipid alterations in frozen-stored minced muscle of Atlantic mackerel, *J. Agric. Food Chem*., 54, 3324, 2006.
120. Chaijan, M. et al., The effect of freezing and aldehydes on the interaction between fish myoglobin and myofibrillar proteins, *J. Agric. Food Chem*., 55, 4562, 2007.
121. Mørkøre, T. and Lilleholt, R., Impact of freezing temperature on quality of farmed Atlantic cod, *J. Texture Stud*., 38, 457, 2007.
122. Ozbay, G., Spencer, K., and Gill, T.A., Investigation of protein denaturation and pigment fading in farmed steelhead (*Onchorhychus mykiss*) fillets during frozen storage, *J. Food Process. Preserv*., 30, 208, 2006.
123. Sinnhuber, R.O. et al., Radiation sterilization of pre-fried cod and halibut patties, *J. Food Technol*., 22, 1570, 1984.
124. Paredes, M.D.C. and Baker, R.C., Physical, chemical and sensory changes during thermal processing of three species of canned fish, *J. Food Process. Preserv*., 12, 71, 1988.
125. English, P.M. et al., Effects of tripolyphosphate dips on the quality of thermally processed mullet (*Mugil cephalus*), *J. Food Sci*., 53, 1319, 1988.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

126. Requena, D.D. et al., Detection of discoloration in thermally processed blue crab meat, *J. Sci. Food Agric.*, 79, 786, 1999.
127. Bhattacharya, S., Choudhury, G.S., and Studebaker, S., Color changes during thermal processing of Pacific chum salmon, *J. Aquat. Food Prod. Technol.*, 3, 39, 1994.
128. Pullela, S.V. et al., Quality comparison of aquacultured pacu (*Piaractus mesopotamicus*) fillets with other aquacultured fish fillets using subjective and objective sensorial traits, *J. Aquat. Food Prod. Technol.*, 9, 65, 2000.
129. Skrede, G. and Storebakken, T., Instrumental colour analysis of farmed and wild Atlantic salmon when raw, baked and smoked, *Aquaculture*, 53, 279, 1986.
130. Skrede, G. and Storebakken, T., Characteristics of color in raw, baked and smoked wild and prereared Atlantic salmon, *J. Food Sci.*, 51, 804, 1986.
131. Jensen, C. et al., Effect of dietary levels of fat, α-tocopherol and astaxanthin on colour and lipid oxidation during storage of frozen rainbow trout (*Oncorhynchus mykiss*) and during chill storage of smoked trout, *Z. Lebensm. Unters. Forsch. A*, 207, 189, 1998.
132. Quinones, A., Choubert, G., and Gomez, R., Colour stability of smoked muscle rainbow trout: Packaging effect, *Sci. Aliments*, 23, 132, 2003.
133. Birkeland, S., Haarstad, I., and Bjerkeng, B., Effects of salt-curing procedure and smoking temperature on astaxanthin stability in smoked salmon, *J. Food Sci.*, 69, FEP198, 2004.
134. Rørå, A.M.B., Monfort, M.C., and Espe, M., Effects of country of origin on consumer preference of smoked salmon collected in a French hypermarket, *J. Aquat. Food Prod. Technol.*, 13, 69, 2004.
135. Espe, M. et al., Quality of cold smoked salmon collected in one French hypermarket during a period of 1 year, *LWT—Food Sci. Technol.*, 37, 627, 2004.
136. Rørå, A.M.B. et al., Quality characteristics of farmed Atlantic salmon (*Salmo salar*) fed diets high in soybean or fish oil as affected by cold-smoking temperature, *LWT—Food Sci. Technol.*, 38, 201, 2005.
137. Antoine, F.R. et al., Phosphate pretreatment on smoke adsorption of cold smoked mullet (*Mugil cephalus*), *J. Aquat. Food Prod. Technol.*, 9, 69, 2000.
138. Fernandez-Segovia, I. et al., Structure and color changes due to thermal treatments in desalted cod, *J. Food Process. Preserv.*, 27, 465, 2003.
139. Bal'a, M.F.A., Podalak, R., and Marshall, D.L. Microbial and color quality of fillets obtained from steam-pasteurized deheaded and eviscerated whole catfish, *Food Microbiol.*, 17, 625, 2000.
140. Fagan, J.D. and Gormley, T.R., Effect of sous vide cooking, with freezing, on selected quality parameters of seven fish species in a range of sauces, *Eur. Food Res. Technol.*, 220, 299, 2005.
141. Dvorák, P., Kratochvíl, B., and Grolichová, M., Changes o f colour and pH in fish musculature after ionizing radiation exposure, *Eur. Food Res. Technol.*, 220, 309, 2005.
142. Schubring, R., Comparative study of the DSC pattern, color, texture and water-binding capacity of rainbow trout muscle during heating, *J. Food Process. Preserv.*, 32, 190, 2008.
143. Cardinal, M. et al., Sensory characteristics of cold-smoked Atlantic salmon (*Salmo salar*) from European market and relationships with chemical, physical and microbiological measurements, *Food Res. Int.*, 37, 193, 2004.
144. Kong, F. et al., Kinetics of salmon quality changes during thermal processing, *J. Food Eng.*, 83, 510, 2007.
145. Mørkøre, T. et al., Fat content and fillet shape of Atlantic salmon: Relevance for processing yield and quality of raw and smoked products, *J. Food Sci.*, 66, 1348, 2001.
146. Rørå, A.M.B. and Einen, O., Effects of freezing on quality of cold-smoked salmon based on the measurements of physiochemical characteristics, *J. Food Sci.*, 68, 2123, 2003.
147. Kristinsson, H.G., Danyali, N., and Ua-Angkoon, S., Effect of filtered wood smoke treatment on chemical and microbial changes in mahi mahi fillets, *J. Food Sci.*, 72, C016, 2007.
148. Cruz-Romero, M. et al., Effects of high pressure treatment on physicochemical characteristics of fresh oysters (*Crassostrea gigas*), *Innov. Food Sci. Emerg. Technol.*, 5, 161, 2004.
149. Schubring, R. et al., Off shore high pressure treatment of freshly caught fish, in: *Innovations in Traditional Foods*, Fito, P. and Toldra, F., Eds., Elsevier, London, 2005, p. 1213.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

150. Matser, A.M. et al., Effects of high pressure on colour and texture of fish, *High Press. Res*., 19, 109, 2000.
151. Ashie, I.N.A. and Simpson, B.K., Application of high hydrostatic pressure to control enzyme related fresh seafood texture deterioration, *Food Res. Int*., 29, 569, 1996.
152. Chevalier, D. et al., Effect of pressure shift freezing, air-blast freezing and storage on some biochemical and physical properties of turbot (*Scophthalmus maximus*), *LWT—Food Sci. Technol*., 33, 570, 2000.
153. Schubring, R. et al., Impact of high pressure assisted thawing on the quality of fillets from various fish species, *Innov. Food Sci. Emerg. Technol*., 4, 257, 2003.
154. Sequeira-Munoz, A. et al., Physicochemical changes induced in carp (*Cyprinus carpio*) fillets by high pressure processing at low temperature, *Innov. Food Sci. Emerg. Technol*., 7, 13, 2006.
155. Chéret, R. et al., Effects of high pressure on texture and microstructure of sea bass (*Dicentrarchus labrax* L.) fillets, *J. Food Sci*., 70, E477, 2005.
156. López-Caballero, M.E. et al. A functional chitosan-enriched fish sausage treated by high pressure, *J. Food Sci*., 70, M166, 2005.
157. Uresti, R.M. et al., Restructured products from arrowtooth flounder (*Atheresthes stomias*) using high-pressure treatments, *Eur. Food Res. Technol*., 220, 113, 2005.
158. Tabilo-Munizaga, G. and Barbosa-Cánovas, G.V., Color and textural parameters of pressurized and heat-treated surimi gels as affected by potato starch and egg white, *Food Res. Int*., 37, 767, 2004.
159. Ramirez-Suarez, J.C. and Morrissey, M.T., Effect of high pressure processing (HPP) on shelf life of albacore tuna (*Thunnus alalunga*) minced muscle. *Innov. Food Sci. Emerg. Technol*., 7, 19, 2006.
160. Amanatidou, A. et al., Effect of combined application of high pressure treatment and modified atmospheres on the shelf life of fresh Atlantic salmon. *Innov. Food Sci. Emerg. Technol*., 1, 87, 2000.
161. Hwang, J.-S., Lai, K.-M., and Hsu, K.-C., Changes in textural and rheological properties of gels from tilapia muscle proteins induced by high pressure and setting. *Food Chem*., 104, 746, 2007.
162. Tironi, V., LeBail, A., and de Lamballerie, M., Effects of pressure-shift freezing and pressure-assisted thawing on sea bass (*Dicentrarchus labrax*) quality, *J. Food Sci*., 72, C381, 2007.
163. Yagiz, Y. et al., Effect of high pressure treatment on the quality of rainbow trout (*Oncorhynchus mykiss*) and mahi mahi (*Coryphaena hippurus*), *J. Food Sci*., 72, C509, 2007.
164. Gómez-Estaca, J., Gómez-Guillén, M.C., and Montero, P., High pressure effects on the quality and preservation of cold-smoked dolphinfish (*Coryphaena hippurus*) fillets, *Food Chem*., 102, 1250, 2007.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 13

Instrumental Texture

Isabel Sánchez-Alonso, Marta Barroso,
and Mercedes Careche

Contents

13.1 Introduction 229
13.2 Selection of the Test Procedure and Sample Preparation 230
13.3 Instrumental Texture 231
13.3.1 Kramer Test 231
13.3.2 Warner–Bratzler Test 231
13.3.3 Puncture Test 232
13.3.4 Tension Analysis 233
13.3.5 Compression Test 233
13.3.6 Texture Profile Analysis 234
13.3.7 Viscoelastic Methods 235
13.3.8 Stress Relaxation Test 235
13.3.8.1 Creep Test 235
13.3.8.2 Small Amplitude Oscillatory Test 236
13.4 Texture Measurement for Quality Assessment 236
13.5 Conclusion 237
References 237

13.1 Introduction

The consumption quality of fish and fish products depend largely on their texture characteristics. It can be considered that the complex structural configurations, which comprise contractile muscle fibers, are largely responsible for these characteristics. Fish muscle fibers are generally much

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

shorter than in their counterparts mammals and birds. Instead of being connected to tendons, they are bound together, one cell deep with their ends attached to sheets of connective tissue called myocommata which separate one block of cells from another. On heating, the myocommata which are composed largely of the protein collagen are broken down releasing the myotomes, which are the characteristic flakes of cooked fish fillets.[1]

The texture of fish can be affected by many factors. These include species differences, biological condition of the fish, methods of catch or slaughter, storage and processing conditions, or culinary treatments. In particular, after the death of the fish, a number of changes associated with the onset and resolution of *rigor mortis* occur, so that before *rigor* the muscle is soft and elastic, in *rigor*, muscle becomes hard due to the contraction of the fibers forming the actomyosin complex, and with its resolution, the muscle becomes soft and less elastic. During frozen storage, one of the frequently used preservation methods, fish muscle may suffer from a series of unwanted changes in texture, especially in some lean species. These changes result in a hard and dry product, and it has been shown that this process is accompanied by myofibrillar proteins aggregation.

Szczesniak[2,3] has reviewed the complexity of texture in foods, the perception of texture, and the consumer attitudes toward this property, as well as the most complete sensory method, the Sensory Texture Profile.[2,3] Nonoral methods commonly performed in the fish sector by pressing parts of the fish body with the finger are of high importance for fish inspection, and have been incorporated as parameters that comprise the Quality Index Method (QIM).[4]

Alongside with the development of sensory texture, many instrumental methods have been developed for measuring the textural properties of foods[5,6] and fish in particular.[7–9] They have been classified in three groups[5]: (i) fundamental, when well-defined rheological properties are measured; (ii) empirical, when instrumental parameters correlate with texture measured by sensory tests; (iii) imitative, which are those tests that resemble the conditions to which the food material is subjected in practice. Most of the reported data on fish flesh texture for quality assessment are based on mechanical tests that are empirical or imitative.

This chapter will describe the different instrumental texture measurements as applied in fish and some fish products with examples on their use in different types of seafood products and conditions.

13.2 Selection of the Test Procedure and Sample Preparation

The selection of the type of test and operating conditions depend on the material and purpose of the study, within the restrictions imposed by the geometry, structure, and fragility of the fish and fish products. For example, different tests may be more suitable depending on the type of sample (e.g., pieces of fish muscle, squid mantle, and *surimi* gels). The purpose of the study may have an additional effect on the selection of the test procedure or even the instrument of choice. For example, whereas for quality control, a fast, simple, and nondestructive method is required, for other applications this may not be necessary. It also depends on the properties to be measured, e.g., overall properties or of some structural parts (connective tissue vs. myotomes). In general terms, the overall size and shape of the fish is important, especially when the analyses are to be performed in the whole specimen, normally with nondestructive purposes. The operational time for a given test may be also important in order to avoid ageing of the material. For example, some rheological tests in which the fish sample is under a given deformation for a long time may be only suited for some applications.

The size and shape characteristics of the fish and fish products often make the preparation of homogeneous samples a difficult task. When analyses are to be performed in fish muscle, its complex structure in terms of organization and orientation of the fibers and connective tissue, as well

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

as the fragility of the overall structure are factors to be taken into account. Some of the methods (e.g., Kramer or puncture tests) may render different results depending on the orientation of the fibers. Another example constitutes the effect of cooking for some of the measurements, such as compression. In some species, myotomes will slide past each other with even a gentle pressure exerted. This can lead to some measurement errors. These aspects will be discussed within each of the methods in the next section.

13.3 Instrumental Texture

The most used methods for the analysis of seafood products are the Kramer, Warner–Braztler, puncture, tensile and compression tests, texture profile analysis (TPA), and viscoelastic methods such as stress relaxation, creep, and small amplitude oscillatory measurements.

13.3.1 Kramer Test

It can be measured using the Kramer shear-compression cell. It was originally developed by Kramer et al.[10] The standard cell is a multibladed fixture: the upper part holds 10 blades, and the lower part or cell, where the food sample is placed, is a case with slots to guide the blades. These pass through the food, and the experiment stops when they have completely run through the sample. During the test, complex combinations of compression, extrusion, shear, and friction occur.[5]

Several factors affecting the performance of the cell including cell volume,[11] and number and thickness of the blades[12] have been investigated. There are many examples in the literature using, besides the original 10-blade cell,[13–15] some modified cells, the most popular being the stable micro systems (SMS) device with five blades with a plexiglas wall in the front part, which allows to see the development of the analysis.[16–18]

For fish fillets, analysis can be performed both, perpendicular or parallel to the lengthwise of the sample, but the perpendicular setup gives better results.[19] Few authors report the orientation of the sample,[13,20] despite its importance. Samples of homogeneous structure can be prepared as parallelepipeds but in many cases, e.g., with fish fillets, the thickness can be controlled only to a certain extent. An alternative is to flake the cooked fillets by hand and to place them as a uniform layer in the Kramer cell.[21,22] Other authors have chosen to dice the fish muscle and evenly spread a fixed amount of it in a random fashion.[14,23]

The parameters usually measured include maximum force per sample weight, slope, and energy of the force–deformation curve. Although in the laboratory a highly linear relationship between maximum force and sample weight has been shown for *surimi*, this could not be found for fillets. Thus, as suggested previously based on food products other than fish,[5] it is advised to use a constant weight of sample for the analysis.

A wide variety of conditions, which affect the overall texture of fish, can be successfully assayed with the Kramer test.[7] However, sample preparation is time consuming, and there is a relatively high amount of material needed to perform the test, and therefore, it may be unsuitable for some applications.

13.3.2 Warner–Bratzler Test

This test was developed by Warner[24] and Bratzler.[25] It is performed with a device that consists of a blade with two cutting edges forming an angle of 60°, which penetrates another device with a slot.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The blade cuts the sample like a guillotine and is subjected to a combination of tension, compression, and shearing.[5] Usually the parameter measured is the maximum force exerted during the shearing. However, in raw fish, there are two peaks in the force–deformation curve which can give distinct information, so that, following the method proposed by Möller in beef samples,[26] the first peak is attributed to the muscle fibers and the second, which is sharper and larger, to the connective tissue[27–30]. There are several methods similar to the Warner–Bratzler (W–B) test. One of them uses a Fish Shearing Device (FSD) that consists of a blade, which cuts the sample as it traverses a rectangular or circular device.[30]

Moreover, in this test it is important to take into account how the fibers are oriented with respect to the blade,[7] and also the relationship between diameter or cross-sectional area of the test samples.[5] One of the problems of W–B is the difficulty of performing the test with small pieces of fish muscle. The shearing takes place in a localized area of the muscle, causing distortion of the muscle fibers.[13] Another drawback is that the cell needs frequent dismounting for cleaning and frequent calibration.[31] Nevertheless, in studies where different instrumental methods have been compared, the shear test has been considered slightly more sensitive for some applications than, for example, TPA.[32,33]

13.3.3 Puncture Test

Puncture test is exerted with a plunger that is pushed into the fish sample. When the punch begins to penetrate into the food there is a change in slope called the yield point, which marks the instant when the punch begins to break the food.[5] Force at the point of rupture, slope and energy of the force–deformation curve, or the depth of penetration over a constant time are the parameters measured.[7] In this test, the sample is subjected to a combination of compression and shearing in proportion to the area and perimeter of the cross-section of the plunger. Plungers with different area/perimeter ratios can be used to obtain the compression and shear coefficients, by plotting the puncture force measured at the yield point (F)/area (or F/perimeter) versus 1/diameter (or diameter).[34]

One of the requirements of this test is that the sample size should be much larger than the punch. In thin samples such as some fish fillets, there is a risk of compressing them against the support plate, so that the test is a combination of puncture and compression, or even full compression.[5]

Sample orientation has an effect on the test when fish fillets are analyzed. They have been measured perpendicularly[35] or parallelly[36] to the orientation of the muscle fibers and regarded as an estimation of fish firmness or cohesiveness respectively.[37] Moreover, when the measurement is performed in conditions so that there is no direct contact of the puncture probe with the myocommata, the measurement has been interpreted as an estimation of the fibers blocks toughness.[38]

The "punch and die test"[39] is a variation of the puncture test, suitable for cases when the sample is thin. In this case, the support plate contains a hole whose diameter is about the same size as the punch diameter. The parameters measured are maximum shear stress, which is related to the maximum force generated by the punch, stiffness, related to the initial slope of the force–deformation curve, and strain at failure, which depends on the deformation of the sample when the punch force is maximum.[39,40] For a given punch diameter, these parameters are dependent on the sample thickness and volume, which are taken into account for obtaining normalized data.[39] Johnson et al.[41] applied this test both in flakes extracted from the fillet and in the fish fillet.

The puncture test is the most popular gel measurement technique used in the industry for evaluating *surimi* quality. The recorded peak force at break and the depth of penetration (deformation) often are multiplied together to give the gel strength that is used in the Japanese grading

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

standards.[42] Since *surimi* gels with different texture properties may render the same gel strength, it has been proposed that force and deformation values should be expressed individually to indicate the gel functionality of *surimi*.[43]

13.3.4 Tension Analysis

For tension analysis samples are prepared in strips or dumb-bell shaped samples. It is performed by holding them with two parallel clamps, one of which is fixed, and the other moves away at a constant rate.[5] The measured parameters are maximum force or tensile strength and energy. The force deformation curves can be corrected to true stress–strain relationship. The overall stiffness and the hardening index can be calculated from the constant and slope of the linear curve.[44]

A drawback of this method is that during the tension test, there is a risk of scattering of the point of rupture. Slipping or premature breaking in the clamps can also occur.[5] This test is widely applied in materials such as squid mantle.[44–46]

13.3.5 Compression Test

Compression analysis is performed upon application of uniaxial compression force, generally, between two parallel flat surfaces. If the force applied is insufficient to damage the sample, it can be considered a nondestructive test.[5] The compression can be exerted to a given distance, percentage deformation, or at a set force. For a true compression test, the probe should be much larger than the sample. From the force–deformation curves, the slope, degree of deformation produced by a set force, and energy calculated by the area under the force–deformation curve, can be calculated.[7] As in other tests the force–time curves can be transformed to true stress–strain relationships.[47] These authors proposed for fish fillets, the use of a compressive deformability modulus derived from the true stress–strain relationships, which is representative of a material's overall resistance to deformation.

There are a number of parameters that have a high influence on the force–deformation curves. These include the deformation rate, the friction at the contact surfaces, and the physical dimensions of the samples.[47–49] The latter is important for fish and fish products, since making homogeneous samples can be a problem due to the special size and shape characteristics of these food samples. In this sense, caution should be taken with interpretation of data when preparing samples with different height to diameter ratio, for example when measuring the compressive properties along the fish fillet. Another factor to be considered is the influence of the shape of the contact bodies. This is well documented for agricultural products such as cereal grains[50,51] in which several methods have been described for the calculation of the apparent modulus of elasticity taking into account the shape of these contact bodies.

Several parameters such as compression speed, deformation level, and thickness of the material have been assayed in fish muscle, in order to choose the best condition for the study of factors/technologies affecting the quality of fish.[31,35,52]

In cooked fish samples the myotomes can fall apart when compressed in the texturometer[53] and due to this, some authors do not consider the compression test suitable in cooked products.[13] The solution of coating the machine surfaces with an abrasive material has been adopted in some cases.[54]

In many applications, the methodological conditions do not comply with the requirements for a true compression test. In fish, they are usually designed to resemble the "finger test." In these

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

cases, sample geometries, which are larger than the probe compressing the food, are used, often performing the test directly in the fillets or the whole fish, with varying and sometimes small, thickness along the sample being measured. In many cases, spherical probes are used. It can be considered that the forces derive from compression, and shear[5,55] and their contribution may vary when the dimensions of the samples (e.g., thickness, shape of the contact surface) are not constant. Nevertheless, there are examples in the literature in which good correlations with the finger test have been found. This is the case in whole fish or fish fillets when studying the effect of ice storage, feeding strategy, and slaughtering method of rainbow trout (*Oncorhynchus mykiss*).[56] Compression test is a good method for the measurement of the overall resistance to deformation. A problem depicted by Hyldig and Nielsen[9] for this test was the difficulty of comparing the results among authors in part due to the fact that conditions of analysis are often not reported, and also because, as discussed previously, many methodological factors can have an influence on the measurements.

13.3.6 Texture Profile Analysis

TPA is an imitative test[57,58] in which the sample is compressed twice, mimicking the action of the jaw. Szczesniak[59] classified the textural terms for solids and semisolid foods, and this was the starting point to the development of a profiling method of texture applicable to both instrumental[57] and sensory[60] measurements, which was soon adapted to the Instron Universal Testing Machine.[61]

The force–deformation curve is analyzed to determine a number of texture parameters, five measured and two calculated. They were originally defined as hardness, cohesiveness, elasticity, adhesiveness, brittleness, chewiness, and gumminess.[57] Nowadays, the most used physical definitions of the mechanical texture attributes are[62,63]:

- *Hardness* is defined as "the peak force during the first compression cycle" (first bite) in Newtons.
- *Cohesiveness* is defined as "the ratio of the positive force area during the second compression portion to that during the first compression, excluding the areas under the decompression portion in each cycle." Cohesiveness is dimensionless.
- *Springiness* (originally called elasticity) is defined as "the height that the food recovers during the time that elapses between the end of the first bite and the start of the second bite." Results are expressed commonly in mm.
- *Adhesiveness* is defined as "the negative force area for the first bite, representing the work (N × mm) necessary to pull the plunger away from the food sample."
- *Fracturability* (originally called brittleness) is defined as "the force in Newtons at the first significant break in curve during the probe's first compression." Not all products fracture but when they do fracture the force falls off.
- *Gumminess* is defined as "the product of hardness × cohesiveness" in Newtons. Gumminess only applies to semisolid products.
- *Chewiness* is defined as "the product of gumminess × springiness" (which is equivalent to hardness × cohesiveness × springiness). Chewiness measured a work (N × mm) and only applies for solid products.

Fish and fish products including *surimi* gels have been analyzed using TPA. Breene[64] and Pons and Fiszman[55] reviewed the TPA analysis in terms of instrumentation, testing conditions, terminology,

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and the time evolution of the main concepts. This test has been applied for fish and fish products in very different experimental conditions. As in the compression test, the size of the compressing units together with the sample size affects the type of forces measured. For the analysis of whole fish, fillets, and mince products, both flat-ended plungers and spherical probes[65,66] have been used. The compression percentages also varied depending on whether the test was aimed to be performed in destructive or nondestructive conditions. The effect of different depths of compression and percentages of deformation has also been analyzed.[32]

In general, it is considered that hardness correlates very well with sensory assessment; however, other parameters such as springiness and cohesiveness render low correlations.[2] It is a very popular method but in fish muscle it has been actually questioned the need of a double compression for most applications[9] since hardness and fracturability are obtained from the first compression cycle.

13.3.7 Viscoelastic Methods

Fish can be considered as a viscoelastic solid and as such, exhibits some of the elastic properties, characteristic of solids, and some flow properties, characteristic of liquids. In a viscoelastic solid, there is an instantaneous deformation upon initial application of the force, and the material continues to deform while the force is being applied. When the rheological properties are only dependent on time, the material displays linear viscoelastic behavior. Nonlinear viscoelasticity is shown when the rheological parameters depend also on other parameters such as magnitude of the stress applied. Most foods behave as linear viscoelastic in a short range of strain.[5,67]

13.3.8 Stress Relaxation Test

In this test, the sample is subjected to a sudden deformation and the force required to hold the deformation constant is measured as a function of time. This test provides several parameters such as relaxation times, viscous, and elastic moduli, as well as the "degree of solidity" of the food. The relaxation curves are usually fitted to nonlinear regression, with two or three exponential terms.[67,68]

Stress relaxation tests in seafood products have mostly been used in *surimi* gels, but other applications include fish myofibrillar protein films,[69] fish muscle,[70–76] fish protein concentrate,[77] and squid mantle.[78,79]

Stress relaxation test has been applied in whole cod (*Gadus morhua*) stored in ice and frozen stored hake (*Merluccius capensis* and *paradoxus*) with the aim of developing a nondestructive method that could correlate with sensory texture changes.[80,81] It was shown that stress relaxation is easy to perform, required little sample preparation, and could be used for quality assessment because good agreement was found between the parameters extracted from stress relaxation and nonoral, low deformation sensory texture parameters.

13.3.8.1 Creep Test

In this test, a given stress is applied to the sample, and the displacement required to hold it constant is measured as the function of time. When the stress is removed, the recovery over time is recorded.[67] Creep test has been mostly used for the study of the rheological behavior of gels[82] but there are also examples of the use of this method in fish muscle.[83,84]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

A portable instrument was developed by Botta[85,86] to determine a texture index for raw Atlantic cod (*G. morhua*) fillets. The test, which can be considered to be based on a fast creep test, rendered very good agreement with sensory texture measurements performed by trained assessors. Nesvadba[87] measured the creep compliance with a new hand-held prototype for cod (*G. morhua*) and concluded that it is possible to construct a hand-held portable instrument for determining the texture of fish in industrial settings.

13.3.8.2 Small Amplitude Oscillatory Test

In the dynamic tests, a food sample is subjected to a small sinusoidal oscillating strain or deformation varying harmonically along the time at fixed or changeable frequency.[88,89] The sample is usually placed between a cone and plate or parallel plates mounted in a controlled stress rheometer. The cone or plate is made to oscillate about a central point with a sinusoidal angular velocity at low amplitude while the shear stress is measured.[5] The experimental shear stress–time curve can be separated into two components: an in phase or real component (G') associated with the storage of energy associated to elastic behavior and an out of phase or imaginary component (G'') associated with the loss of energy due to viscous behavior. The phase angle (δ) between stress and strain can be obtained. Perfectly elastic or viscous materials would render $\delta = 0$ or 90°, respectively.[67,87,90] *Surimi* and other protein gels are normally quite elastic so values of δ are less than 10°.[43]

Nesvadba[87] proposed the use of an oscillatory test for the study of fish freshness and frozen storage. In addition, glass transition temperature in abalone has been studied using this test.[91,92] However, most applications are related to the gelation process of *surimi*.[43,82,93,94] These gelation studies are usually performed at a constant frequency (less than 1 Hz) with varying time and/or temperature.[95]

13.4 Texture Measurement for Quality Assessment

Along with other applications of the use of instrumental texture analysis, the quality classification, or prediction based on some of the aforementioned instrumental methods has been a subject of interest in several seafood products applications. One of the approaches has been to classify frozen fish into several quality categories according to their Kramer, Warner–Bratzler, and puncture tests parameters. Thus, in frozen stored hake (*Merluccius* spp.), samples can be classified by this procedure into different time–temperature conditions.[96] In some fish species, frozen storage time at a given temperature can be regarded as an estimation of their quality. A linear regression model with time as the variable to be predicted, and the parameters from the aforementioned tests as independent variables, can be performed. This was the approach used in frozen hake stored at –20°C for up to 2 years[97] with good results.

Instrumental texture analysis has been used in combination with other methods to assess different quality features of fish, such as electronic nose and colormeter measurements. The method has been termed Artificial Quality Index (AQI),[98,99] and it is based on the same principles as those of the sensory method named QIM. Thus, data from the different instrumental equipment have been calibrated with their corresponding sensory attributes from the QIM. For this AQI, the stress relaxation test has been the method of choice, rendering good results for ice-stored cod.[80,100] The AQI concept could be applied in small, portable instruments,[87] and it can be as accurate and precise as the QIM.[99] Thus, the replacement of trained sensory panels by a combination of instrumental methods that mimic human senses is a promising approach. The concept was designed

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

using ice stored cod as the model species, and later it was applied in sardine during refrigerated storage with good results.[101]

13.5 Conclusion

There is a wide range of methods to analyze the instrumental texture of fish and fish products. For those products in which the integrity of the fish muscle is maintained, its complex structure imposes some restrictions to the application of some of the tests. Except for quality control, in which it is needed to perform simple and fast tests, for most applications the combination of more than one method can be of great value.

References

1. Mackie, I.M. The effects of post-mortem storage of fish muscle proteins, In: *Methods to Determine the Freshness of Fish in Research and Industry*. Olafsdóttir, G., Luten, J., Dalgaard, P., Careche, M., Verrez-Bagnis, V., Martinsdóttir, E., and Heia, K., Eds. International Institute of Refrigeration: Paris, France, 185, 1997.
2. Szczesniak, A.S. Sensory texture profiling—Historical and scientific perspectives. *Food Technol*., 52, 54, 1998.
3. Szczesniak, A.S. Texture is a sensory property. *Food Qual. Prefer*., 13, 215, 2002.
4. Bremner, H.A., Olley, J., and Vail, A.M.A. Estimating time-temperature effects by rapid systematic sensory methods. In: *Seafood Quality Determination*. Kramer, D.E. and Liston, J., Eds. Elsevier: Amsterdam, the Netherlands, 413, 1987.
5. Bourne, M.C. Food texture and viscosity: Concept and measurement. In: *Food Texture and Viscosity: Concept and Measurement*. Taylor, S.L., Ed. Academic Press: New York, 2002.
6. van Vliet, T. Rheological classification of foods and instrumental techniques for their study. In: *Food Texture*: *Measurement and Perception*. Rosenthal, A.J., Ed. Aspen Publishers Inc.: Gaithersburg, MD, 65, 1999.
7. Barroso, M., Careche, M., and Borderias, A.J. Quality control of frozen fish using rheological techniques. *Trends Food Sci. Technol*., 9, 223, 1998.
8. Barroso, M., Careche, M., and Borderias, A.J. Evaluation of fish freshness using mechanical methods. In: *Methods to Determine the Freshness of Fish in Research and Industry*. Olafsdottir, G., Luten, J.B., Dalgaard, P., Careche, M., Verrez-Bagnis, V., Martinsdottir, E., and Heia, K., Eds. International Institute of Refrigeration: Paris, France, 355, 1997.
9. Hyldig, G. and Nielsen, D. A review of sensory and instrumental methods used to evaluate the texture of fish muscle. *J. Texture Stud*., 32, 219, 2001.
10. Kramer, A., Burkhardt, G.T., and Rogers, H.P. The Shear-Press, a device for measuring food quality. *The Canner*, 12, 34, 1951.
11. Voisey, P.W. and Kloek, M. Effect of cell-size on the performance of the shear-compression texture test cell. *J. Texture Stud*., 12, 133, 1981.
12. Timbers, G.E., Voisey, P.W., and Kloek, M. Influence of number and thickness of the blades on the performance of the Kramer-type shear-compression cell. *J. Texture Stud*., 16, 303, 1985.
13. Borderias, A.J., Lamua, M., and Tejada, M. Texture analysis of fish fillets and minced fish by both sensory and instrumental methods. *J. Food Technol*., 18, 85, 1983.
14. Krueger, D.J. and Fennema, O.R. Effect of chemical additives on toughening of fillets of frozen Alaska pollack (Theragra chalcogramma). *J. Food Sci*., 54, 1101, 1989.
15. Hallier, A., Chevallier, S., Serot, T., and Prost, C. Freezing-thawing effects on the colour and texture of European catfish flesh. *Int. J. Food Sci. Technol*., 43, 1253, 2008.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

16. Sánchez-Alonso, I. and Borderías, A.J. Technological effect of red grape antioxidant dietary fibre added to minced fish muscle. *Int. J. Food Sci. Technol*., 43, 1009, 2008.
17. Sánchez-Alonso, I., Hají-Maleki, R., and Borderías, A.J. Wheat fiber as a functional ingredient in restructured fish products. *Food Chem*., 100, 1037, 2007.
18. Sánchez-Alonso, I., Solas, M.T., and Borderías, A.J. Physical study of minced fish muscle with a white-grape by-product added as ingredient. *J. Food Sci*., 72, E94, 2007.
19. Taylor, R.G., Fjaera, S.O., and Skjervold, P.O. Salmon fillet texture is determined by myofiber-myofiber and myofiber-myocommata attachment. *J. Food Sci*., 67, 2067, 2002.
20. McKenna, D.R., Nanke, K.E., and Olson, D.G. The effects of irradiation, high hydrostatic pressure, and temperature during pressurization on the characteristics of cooked-reheated salmon and catfish fillets. *J. Food Sci*., 68, 368, 2003.
21. Kramer, D.E. and Peters, M.D. Effect of pH and prefreezing treatment on the texture of yellowtail rockfish (*Sebastes flavidus*) as measured by the Ottawa Texture Measuring System. *J. Food Technol*., 16, 493, 1981.
22. Botta, J.R., Bonnell, G., and Squires, B.E. Effect of method of catching and time of season on sensory quality of fresh raw Atlantic cod (*Gadus morhua*). *J. Food Sci*., 52, 928, 1987.
23. Krivchenia, M. and Fennema, O. Effect of cryoprotectants on frozen whitefish fillets. *J. Food Sci*., 53, 999, 1988.
24. Warner, K.F. Progress report of the mechanical test for tenderness of meat. *Ann. Am. Proc. Soc. Anim. Prod*., 21, 114, 1928.
25. Bratzler, L.J. Determining the tenderness of meat by use of the Warner-Bratzler method. *Proceedings of the 2nd Reciprocal Meat Conference*, Kansas City, 117, 1949.
26. Moller, A.J. Analysis of Warner-Bratzler shear pattern with regard to myofibrillar and connective tissue components of tenderness. *Meat Sci*., 5, 247, 1981.
27. Montero, P. and Borderias, J. Influence of age on muscle connective tissue in trout (*Salmo irideus*). *J. Sci. Food Agric*., 51, 261, 1990.
28. Montero, P. and Borderias, J. Behavior of myofibrillar proteins and collagen in hake (*Merluccius merluccius*) muscle during frozen storage and its effect on texture. *Z. Lebensm. Unters. Forsch*., 190, 112, 1990.
29. Montero, P. and Borderias, J. Influence of myofibrillar proteins and collagen aggregation on the texture of frozen hake muscle. In: *Quality Assurance in the Fish Industry*. Huss, H.H., Jakobsen, M., and Liston, J., Eds. Elsevier Science Publishers B.V.: Amsterdam, the Netherlands, 149, 1992.
30. Chamberlain, A.I., Kow, F., and Balasubramaniam, E. Instrumental method for measuring texture of fish. *Food Aust*., 45, 439, 1993.
31. Chung, S.L. and Merritt, J.H. Physical measures of sensory texture in thawed sea scallop meat. *Int. J. Food Sci. Technol*., 26, 207, 1991.
32. Veland, J.O. and Torrissen, O.J. The texture of Atlantic salmon (*Salmo salar*) muscle as measured instrumentally using TPA and Warner-Brazler shear test. *J. Sci. Food Agric*., 79, 1737, 1999.
33. Sigurgisladottir, S., Hafsteinsson, H., Jonsson, A., Lie, O., Nortvedt, R., Thomassen, M., and Torrissen, O. Textural properties of raw salmon fillets as related to sampling method. *J. Food Sci*., 64, 99, 1999.
34. Bourne, M.C. Method for obtaining compression and shear coefficients of foods using cylindrical punches. *J. Texture Stud*., 5, 459, 1975.
35. Orban, E., Sinesio, F., and Paoletti, F. The functional properties of the proteins, texture and the sensory characteristics of frozen sea bream fillets (*Sparus aurata*) from different farming systems. *Lebensm.-Wiss. u-Technol*., 30, 214, 1997.
36. Ando, M., Toyohara, H., Shimizu, Y., and Sakaguchi, M. Validity of a puncture test for evaluating change in muscle firmness of fish during ice storage. *Nippon Suisan Gakkaishi*, 57, 2341, 1991.
37. Izquierdo-Pulido, M.L., Hatae, K., and Haard, N.F. Nucleotide catabolism and changes in texture indices during ice storage of cultured sturgeon, Acipenser transmontanus. *J. Food Biochem*., 16, 173, 1992.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

38. Morzel, M., Heapes, M.M., Reville, W.J., and Arendt, E.K. Textural and ultrastructural changes during processing and storage of lightly preserved salmon (*Salmo salar*) products. *J. Sci. Food Agric.*, 80, 1691, 2000.
39. Segars, R.A., Hamel, R.G., Kapsalis, J.G., and Kluter, R.A. A punch and die test cell for determining the textural qualities of meat. *J. Texture Stud.*, 6, 211, 1975.
40. Sawyer, F.M., Cardello, A.V., Prell, P.A., Johnson, E.A., Segars, R.A., Maller, O., and Kapsalis, J. Sensory and instrumental evaluation of snapper and rockfish species. *J. Food Sci.*, 49, 727, 1984.
41. Johnson, E.A., Peleg, M., Sawyer, F.M., Segars, R.A., and Cardello, A. Mechanical methods of measuring textural characteristics of fish flesh. In: *Refrigeration Science and Technology*. I.I.F./I.I.R.: Boston, MA, 103, 1981.
42. Park, J. and Morrissey, M. The need for developing uniform surimi standards. In: *Quality Control & Quality Assurance for Seafood*. Sylvia, G., Shriver, A. L., and Morrissey, M., Eds. Oregon Sea Grant: Corvallis, OR, pp. 64–71, 1993.
43. Kim, Y.J., Park, J.W., and Yoon, W.B. Rheology and texture properties of surimi gels. In: *Surimi and Surimi Seafood*, 2nd edn., Park, J.W., Ed. 6000 Broken Sound Parkway NW, Suite 300: Boca Raton, FL 33487-2742; CRC Press: Boca Raton, FL, pp. 491–582, 2005.
44. Kuo, J.D., Peleg, M., and Hultin, H.O. Tensile characteristics of squid mantle. *J. Food Sci.*, 55, 369, 1990.
45. Collignan, A. and Montet, D. Tenderizing squid mantle by marination at different pH and temperature levels. *Lebensm.-Wiss. u-Technol.*, 31, 673, 1998.
46. Kagawa, M., Matsumoto, M., Yoneda, C., Mitsuhashi, T., and Hatae, K. Changes in meat texture of three varieties of squid in the early stage of cold storage. *Fisheries Sci.*, 68, 783, 2002.
47. Johnson, E.A., Segars, R.A., Kapsalis, J.G., Normand, M.D., and Peleg, M. Evaluation of the compressive deformability modulus of fresh and cooked fish flesh. *J. Food Sci.*, 45, 1318, 1980.
48. Calzada, J.F. and Peleg, M. Mechanical interpretation of compressive stress-strain relationships of solid foods. *J. Food Sci.*, 43, 1087, 1978.
49. Chu, C.F. and Peleg, M. The compressive behavior of solid food specimens with small height to diameter ratios. *J. Texture Stud.*, 16, 451, 1985.
50. Arnold, P.C. and Mohsenin, N.N. Proposed techniques for axial compression tests on intact agricultural products of convex shape. *Trans. ASAE*, 14, 78, 1971.
51. Mohsenin, N.N. Contact stresses between bodies in compression. In: *Physical Properties of Plant and Animal Materials*, *Vol. 1. Structure, Physical Characteristics and Mechanical Properties*. Mohsenin, N.N., Ed. Gordon & Breach Science Publishers Inc.: New York, pp. 278–308, 1970.
52. Weinberg, Z.G. and Angel, S. Behavior of a formed fish product under the stress-relaxation text. *J. Food Sci.*, 50, 589, 1985.
53. Hatae, K., Yoshimatsu, F., and Matsumoto, J.J. Role of muscle-fibers in contributing firmness of cooked fish. *J. Food Sci.*, 55, 693, 1990.
54. Feinstein, G.R. and Buck, E.M. Relationship of texture to pH and collagen content of yellowtail flounder and cusk. *J. Food Sci.*, 49, 298, 1984.
55. Pons, M. and Fiszman, S.M. Instrumental texture profile analysis with particular reference to gelled systems. *J. Texture Stud.*, 27, 597, 1996.
56. Faergemand, J., Ronsholdt, B., Alsted, N., and Borresen, T. Fillet texture of rainbow-trout as affected by feeding strategy, slaughtering procedure and storage post-mortem. *Water Sci. Technol.*, 31, 225, 1995.
57. Szczesniak, A.S., Brandt, M.A., and Friedman, H.H. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. *J. Food Sci.*, 28, 397, 1963.
58. Friedman, H.H., Whitney, J.E., and Szczesniak, A.S. The texturometer-A new instrument for objective texture measurement. *J. Food Sci.*, 28, 390, 1963.
59. Szczesniak, A.S. Classification of textural characteristics. *J. Food Sci.*, 28, 385, 1963.
60. Brandt, M.A., Skinner, E.Z., and Coleman, J.A. Texture Profile Method. *J. Food Sci.*, 28, 404, 1963.
61. Bourne, M.C. Texture profile of ripening pears. *J. Food Sci.*, 33, 223, 1968.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

62. Bourne, M.C. Texture profile analysis. *Food Technol*., 32, 62, 1978.
63. Bourne, M.C. *Food Texture and Viscosity: Concept and Measurement*, Academic Press: New York, 1982.
64. Breene, W. Application of texture profile analysis to instrumental food texture evaluation. *J. Texture Stud*., 6, 53, 1975.
65. Morkore, T. and Einen, O. Relating sensory and instrumental texture analyses of Atlantic salmon. *J. Food Sci*., 68, 1492, 2003.
66. Carbonell, I., Duran, L., Izquierdo, L., and Costell, E. Texture of cultured gilthead sea bream (*Sparus aurata*): Instrumental and sensory measurement. *J. Texture Stud*., 34, 203, 2003.
67. Mohsenin, N.N. Some basic concepts of rheology. In: *Physical Properties of Plants and Animals Materials, Vol. 1. Structure, Physical Characteristics and Mechanical Properties*. Mohsenin, N.N., Ed. Gordon & Breach Science Publishers Inc.: New York, pp. 88–173, 1970.
68. Peleg, M. Characterization of stress relaxation curves of solid foods. *J. Food Sci*., 44, 277, 1979.
69. Cuq, B., Gontard, N., Cuq, J.L., and Guilbert, S. Rheological model for the mechanical properties of myofibrillar protein-based films. *J. Agric. Food Chem*., 44, 1116, 1996.
70. Iso, N., Mizuno, H., Saito, T., Ohzeki, F., and Yang, L.C. Studies on the rheological properties of heated carp meats. *Bull. Jpn. Soc. Sci. Fish*., 50, 349, 1984.
71. Iso, N., Mizuno, H., Saito, T., Ohzeki, F., and Wang, Z. Studies on the rheological properties of the heated yellowtail meat. *Bull. Jpn. Soc. Sci. Fish*., 50, 2061, 1984.
72. Iso, N., Mizuno, H., Saito, T., Mochizuki, Y., Ishii, K., Okunuki, H., and Miyata, K. The relationships between the rheological properties and the freshness of fish meat. *Bull. Jpn. Soc. Sci. Fish*., 53, 1231, 1987.
73. Kimura, H., Saito, T., Mizuno, H., Ogawa, H., Mochizuki, Y., Suyama, Y., and Iso, N. The rheological properties of salted jellyfish during cooking and dipping in water. *Bull. Jpn. Soc. Sci. Fish*., 57, 463, 1991.
74. Xin, G., Ogawa, H., Tashiro, Y., and Iso, N. Rheological properties and structural changes in raw and cooked abalone meat. *Fisheries Sci*., 67, 314, 2001.
75. Xin, G., Tashiro, Y., and Ogawa, H. The correlation between rheological properties and characteristic values of structure for steamed abalone meat. *Food Sci. Technol. Res*., 8, 304, 2002.
76. Xin, G., Tashiro, Y., and Ogawa, H. Rheological properties and structural changes in steamed and boiled abalone meat. *Fisheries Sci*., 68, 499, 2002.
77. Okazaki, E., Tsukada, K., Kanna, K., and Suzuki, T. Changes of properties of meat-textured fish-protein concentrate during frozen storage. *Bull. Jpn. Soc. Sci. Fish*., 50, 307, 1984.
78. Mochizuki, Y., Mizuno, H., Ogawa, H., Ishimura, K., Tsuchiya, H., Fukuzawa, M., and Iso, N. Rheological properties of cuttlefish and squid raw meat. *Fisheries Sci*., 60, 555, 1994.
79. Mochizuki, Y., Mizuno, H., Ogawa, H., Ishimura, K., Tsuchiya, H., and Iso, H. Changes of rheological properties of cuttlefish and squid meat by heat treatment. *Fisheries Sci*., 61, 680, 1995.
80. Herrero, A.M., Heia, K., and Careche, M. Stress relaxation test for monitoring post mortem textural changes of ice-stored cod (*Gadus morhua*). *J. Food Sci*., 69, FEP178, 2004.
81. Herrero, A.M. and Careche, M. Stress relaxation test to evaluate textural quality of frozen stored Cape hake (*M. capensis* and *M. paradoxus*). *Food Res. Int*., 38, 69, 2005.
82. Campo, L. and Tovar, C.A. Influence of the starch content in the viscoelastic properties of surimi gels. *J. Food Eng*., 84, 140, 2008.
83. Hatae, K., Nakayama, T., Matsui, Y., Shimada, A., and Matsumoto, J.J. Creep compliance behaviours of raw fish muscles in five species. *Bull. Jpn. Soc. Sci. Fish*., 54, 1595, 1988.
84. Yoshioka, K., and Yamamoto, T. Changes of ultrastructure and the physical properties of carp muscle by high pressurization. *Fisheries Sci*., 64, 89, 1998.
85. Botta, J.R. Instrument for nondestructive texture measurement of raw Atlantic cod (*Gadus morhua*) fillets. *J. Food Sci*., 56, 962, 1991.
86. Botta, J.R. Physical methods of evaluating freshness quality. In: *Evaluation of Seafood Freshness Quality*. VCH Publishers Inc.: Weinheim, Germany, pp. 35–63, 1995.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

87. Nesvadba, P. Quality control by instrumental texture measurements. In: *Seafoods—Quality, Technology and Nutraceutical Applications*. Alasavar, C., Taylor, T., Eds. Springer: Berlin, pp. 43–57, 2002.
88. Rao, M.A. Phase transitions, food texture and structure. In: *Texture in Food, Vol. 1: Semi-Solid Foods*. Brian, M., McKenna, Eds. CRC Press: Boca Raton, Boston, New York, Washington, DC, pp. 36–62, 2003.
89. Barnes, H.A., Hutton, J.F., and Walters, K. *An Introduction to Rheology*. Elsevier: Amsterdam, 1993.
90. Gunasekaran, S. and Ak, M.M. Dynamic oscillatory shear testing of foods—Selected applications. *Trends Food Sci. Technol*., 11, 115, 2000.
91. Rahman, M.S., Kasapis, S., Guizani, N., and Amri, O.S. State diagram of tuna meat: Freezing curve and glass transition. *J. Food Eng*., 57, 321, 2003.
92. Sablani, S.S., Kasapis, S., Rahman, M.S., Al Jabri, A., and Al Habsi, N. Sorption isotherms and the state diagram for evaluating stability criteria of abalone. *Food Res. Int*., 37, 915, 2004.
93. Ma, L., Grove, A., and Barbosa-Cánovas, G.V. Viscoelastic characterization of surimi gel: Effects of setting and starch. *J. Food Sci*., 61, 881, 1996.
94. Yoon, W.B., Gunasekaran, S., and Park, J.W. Characterization of thermorheological behavior of Alaska Pollock and Pacific Whiting surimi. *J. Food Sci*., 69, 338, 2004.
95. Hamann, D.D., Purkayastha, S., and Lanier, T.C. Applications of thermal scanning rheology to the study of food gels. In: *Thermal Analysis of Foods*. Harwalker, V.R. and Ma, C.Y., Eds. Elsevier, Barking: Essex, U.K., pp. 306–332, 1990.
96. Barroso, M. Careche, M., Barrios, L., and Borderias, A.J. Frozen hake fillets quality as related to texture and viscosity by mechanical methods. *J. Food Sci*., 63, 793, 1998.
97. Herrero, A.M. and Careche, M. Prediction of frozen storage time of Cape hake (*Merluccius capensis* and *Merluccius paradoxus*) by instrumental methods. *J. Sci. Food Agric*., 86, 2128, 2006.
98. Di Natale, C. Data fusion in MUSTEC: Towards the definition of an artificial quality index. In: *Quality of Fish from Catch to Consumer: Labelling, Monitoring and Traceability*. Luten, J.B., Oehlenschager, J., and Olafsdottir, G., Eds. Wageningen Academic Publishers: Wageningen, the Netherlands, pp. 273–282, 2003.
99. Olafsdottir, G., Nesvadba, P., Di Natale, C., Careche, M., Oehlenschager, J., Tryggvadottir, S.V., Schubring, R., Kroeger, M., Heia, K., Esaiassen, M., Macagnano, A., and Jorgensen, B.A. Multisensor for fish quality determination. *Trends Food Sci. Technol*., 15, 86, 2004.
100. Careche, M., Tryggvadottir, S.V., Herrero, A., Lägel, B., Petermann, U., Schubring, R., and Nesvadba, P. Instrumental methods for measuring texture of fish. In: *Quality of Fish from Catch to Consumer: Labeling, Monitoring and Traceability*. Luten, J.B., Oehlenschager, J., Olafsdottir, G., Eds. Wageningen Academic Publishers: Wageningen, the Netherlands, pp. 189–200, 2003.
101. Macagnano, A., Careche, M., Herrero, A., Paolesse, R., Martinelli, E., Pennazza, G., Carmona, P., D'Amico, A., and Di Natale, C. A model to predict fish quality from instrumental features. *Sens. Actuators B: Chem*., 111, 293, 2005.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 14

Aroma

John Stephen Elmore

Contents

14.1 Introduction 244
14.2 Reasons for Studying Fish and Seafood Aroma 244
14.2.1 Identification of Those Compounds, Which Are Important in Desirable Cooked Fish and Seafood Flavor 244
14.2.2 Identification of Compounds That Give Undesirable Aroma and Flavor to Cooked and Uncooked Fish and Seafood 245
14.2.3 Measuring the Effect of Pre- and Postslaughter Treatments 245
14.3 Sample Preparation 246
14.4 Aroma Extraction Methods 246
14.4.1 Solvent Extraction 246
14.4.2 Steam Distillation and Vacuum Steam Distillation 247
14.4.3 Simultaneous Distillation/Extraction 247
14.4.4 High Vacuum Distillation/Solvent-Assisted Flavor Evaporation 249
14.4.5 Headspace Analysis 249
14.4.6 Adsorption 250
14.4.7 Solid-Phase Microextraction 251
14.4.8 Analysis of Trimethylamine Oxide Breakdown Products 253
14.4.9 Analysis of Geosmin and 2-Methylisoborneol 253
14.5 Separation and Identification of Aroma Components 253
14.6 Quantification of Aroma Components 254
14.7 Detection of Components of Sensory Significance 255
14.8 The Electronic Nose 256
14.9 Future Developments 256
References 257

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

14.1 Introduction

Numerous species of fish and shellfish are eaten across the world and, for many of these species, the chemical compounds that contribute to their aroma have been studied. These compounds are generally of low molecular weight (less than 300 Da), volatile, and present at very low concentrations (parts per million or less); most are of limited solubility in water.

It is often necessary to characterize fish and seafood aroma, for reasons which will be described later in the chapter. In order to do so, one would extract the volatile material from the food matrix, concentrate it, and attempt to separate and identify the individual components. By far the most widely used technique for the separation and identification of aroma compounds in extracts is gas chromatography–mass spectrometry (GC–MS), and unless stated otherwise, it can be assumed that, in all examples discussed in this chapter, GC–MS was used.

As far as possible, the extract should contain only the volatile components, in the same relative proportions as in the food itself, without the introduction of artifacts. However, to obtain such an extract is an extremely difficult task, and so numerous complementary extraction techniques exist, which allow the flavor chemist to obtain a complete knowledge of those compounds that are present in fish aroma. The components which are responsible for fish aroma are present in extremely small quantities, compared with the major constituents, of which water is the most abundant. A number of isolation techniques exist, all based on utilizing the physical properties of the aroma compounds to separate them from the food matrix and from water. The most widely used isolation techniques for the analysis of fish and seafood aroma will be described in this chapter.

Often, a detailed analysis of individual compounds may not be necessary. An analytical technique which provides a "fingerprint" of the sample under study may be all that is required; for example, to distinguish fish from different species, or to determine if a piece of fish is of sufficient freshness. Electronic noses are detectors, which use gas sensor arrays or mass spectrometers, the latter sometimes known as MS-noses, to discriminate between samples, without the need for an extraction or separation. The use of electronic noses to discriminate between fish samples will also be discussed in this chapter.

14.2 Reasons for Studying Fish and Seafood Aroma

Studies on fish and seafood aroma can broadly be divided into three areas:

1. Identification of those compounds, which are important in desirable cooked fish and seafood flavor;
2. Identification of compounds, which give undesirable aroma and flavor to cooked and uncooked fish and seafood;
3. Examination of how different pre- and postslaughter treatments may affect aroma volatiles.

14.2.1 Identification of Those Compounds, Which Are Important in Desirable Cooked Fish and Seafood Flavor

Aroma extract dilution analysis (AEDA), which will be described later in the chapter, is a technique, which is often used to identify the important aroma compounds in food. For example, (*Z*)-1,5-octadien-3-one, (*E*,*Z*)-2,6-nonadienal, and methional are all potent odorants of fresh,

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

boiled trout, salmon, and cod, while propionaldehyde, acetaldehyde, and methional are important in boiled salmon and cod, and (*E*,*E*)-2,4-decadienal is important in boiled cod alone [1–3]. In studies on cooked shellfish, 2-acetyl-1-pyrroline, having a nutty, popcorn-like odor, 2,3-butanedione (sour, creamy), 2-methyl-3-furanthiol (cooked rice, meaty), methional (salty, soy sauce-like), and 2-acetyl-2-thiazoline (also nutty, popcorn-like) all contribute to the desirable aromas of cooked crab, lobster, crayfish, prawn, and shrimp [4–7].

14.2.2 Identification of Compounds That Give Undesirable Aroma and Flavor to Cooked and Uncooked Fish and Seafood

Several compounds contribute to off-flavors in fish. Off-flavors can be formed through deterioration of fish on storage or may be present in the fish, as a result of their environment [8].

Trimethylamine oxide (TMAO) is produced in most species of marine fish and shellfish during digestion and breaks down enzymatically on storage to give trimethylamine (TMA), dimethylamine, and formaldehyde [9]. High TMA levels lead to low sensory scores, and TMA measurement has often been used to monitor spoilage.

Fish and seafood are high in polyunsaturated fatty acids, and lipid oxidation readily occurs in both chilled and frozen fish. Lipid-derived compounds implicated in undesirable fishy aromas in both cooked and uncooked fish and seafood include 2,4,7-decatrienal, (*Z*)-3-hexenal, (*Z*,*Z*)-3,6-nonadienal, (*Z*)-4-heptenal, and 1-octen-3-one [6,8,10]. Methods for measuring freshness quality will be discussed in a later chapter.

Two compounds often implicated in the spoilage of freshwater fish through environmental contamination are geosmin and 2-methylisoborneol. Both compounds are microbial metabolites readily absorbed by fish, and both compounds contribute musty, earthy off-flavors. Other common taints are a garlic off-flavor in prawns and an iodoform off-flavor in prawns and shrimps [11]. The iodoform taint is caused by high levels of bromophenols; at lower levels these compounds contribute to desirable marine flavors in prawns [12].

14.2.3 Measuring the Effect of Pre- and Postslaughter Treatments

The effects of different dietary lipids on the aroma volatiles of turbot [13], brown trout [14,15], tench [16], and carp [17] have been studied. Different types of algae affect the volatiles from oysters [18] and bromophenol levels in green grouper [19]. Aroma compounds from wild and farmed fish have also been compared for ayu [20], Atlantic salmon [21], gilthead sea bream [22,23], trout [24], turbot [25], and prawns [12].

The effect of refrigerated and/or frozen storage on aroma compounds, other than TMA, has been widely studied, in fish, such as cod [2,3,10,26,27], trout [1,10], salmon [3,28], whiting [26], tuna [29], whitefish [30], Antarctic krill [31], hake [32], sardine [33–35], and mackerel [26,36], as well as fish oils, such as menhaden, sardine, and bonito oil [37].

Aroma composition may be affected by canning [37–45], smoking [46–56], salting [57], fermentation [58–64], drying [65], pickling [66], and irradiation [67]. Fish sauce is an important ingredient in Asian cuisine, produced from a mixture of fish and salt that has been allowed to ferment for a period of greater than 6 months at 30°C–35°C [68]. Fish sauce has a distinctive aroma, which has been widely studied [69–73]. The use of seafood processing waste has attracted attention. The water used to boil, for example, crab and crayfish, and the inedible material remaining after processing, can be used to prepare seafood flavor extracts [74–77].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

14.3 Sample Preparation

There are a number of factors that need to be considered, when analyzing fish and seafood aroma. The meat from fish is relatively homogeneous, compared to that of meat, where the presence of adipose tissue may influence how the meat is cooked. Even so, one consideration may be whether to cook the fish whole, or as a fillet, with or without skin attached, or to reduce variation by mincing the fish and forming a patty from the muscle. Grilling, boiling, pressure-cooking, baking, and frying are some of the cooking processes, which could be used. The sample could be cooked for a constant time or to a constant internal temperature. A well-done fish will have a different aroma profile to a lightly cooked fish, and the degree of cooking should be considered before analysis commences. It is important to employ reproducible methods when cooking the sample. This may be difficult when grilling or frying. Pressure-cooking, although not as commonly used in the kitchen as some of the other methods, has an advantage in that there is no sample loss and temperature control is straightforward.

When analyzing a cooked sample, it is important to extract the sample as soon after cooking as possible. Otherwise off-flavors may be generated when it is reheated. There is no reason why the extraction cannot be carried out at room temperature, although at higher temperatures the amount of volatile material extracted will increase. Heated food is normally eaten at around 60°C. Variation within the sample should be minimized by chopping, or mincing, or homogenization and appropriate replication should be performed, in order that effective comparison between treatments may be achieved. Large variations exist in all naturally occurring foodstuffs, and at least four analyses per treatment would always be appropriate when studying seafood.

14.4 Aroma Extraction Methods

The reasons for choosing a particular aroma extraction method have been discussed in detail [78]. If accurate quantification of one particular aroma compound is required, the extraction method should be selected to maximize the extraction of that particular compound, without generating that compound *in situ*. However, if a full aroma profile is required, another extraction method or methods may be more suitable. Some extraction techniques only provide enough extract for one analysis, whereas others provide a liquid sample, which can be used for several different experiments.

14.4.1 Solvent Extraction

Direct extraction of fish and seafood with an organic solvent is of limited use, because the extract will contain much nonvolatile matter, particularly lipid. However, supercritical fluid extraction (SFE) with supercritical carbon dioxide can be a useful technique for the extraction of aromas. Its solvating qualities can be altered by changing the pressure or temperature at which the extraction takes place, and under ideal conditions supercritical carbon dioxide exhibits a strong affinity for most aroma compounds, while most nonvolatile constituents are insoluble. The ease of removal of the solvent, after extraction, to give a concentrated aroma extract, is another attractive feature of SFE. Aro et al. used SFE to extract semivolatile compounds from Baltic herring; the compounds were analyzed by supercritical fluid chromatography [79]. Another way SFE can be used is to remove off-notes from tuna fish oil [80].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

14.4.2 Steam Distillation and Vacuum Steam Distillation

Steam distillation finds application in the analyses of volatiles from beverages and high water-content foods, although it is less applicable to fats and oils. It has the disadvantage that the large quantities of aqueous distillate require further extraction with a solvent, to separate the volatiles from the water. Concentration of the extract is then necessary. The formation of artifacts may also be a problem. The technique has been used to examine the odor of Antarctic krill [81], the components of cuttlefish oil [82], and the effect of irradiation on shrimp volatiles [67].

If steam distillation is performed under high vacuum, less sample degradation occurs. For example, Triqui and Reineccius [83,84] performed steam distillation of anchovy volatiles under vacuum at around 57°C. They extracted the distillate with dichloromethane and then concentrated the extract by microdistillation. A similar technique was used to examine the character-impact compounds of raw oyster [18,85,86]. The vacuum was strong enough to perform the extraction at room temperature and volatiles were condensed in a flask at 2°C, which was connected to three liquid nitrogen-cooled cold traps. Again, the distillate was dissolved in dichloromethane and then concentrated. This method was also to examine the aroma compounds in brown trout [14,87], turbot [13], and mussels [88,89].

14.4.3 Simultaneous Distillation/Extraction

One of the most widely used techniques in aroma analysis combines steam distillation with solvent extraction in a Likens–Nickerson apparatus (Figure 14.1), which was first reported in 1964 for the extraction of hop oil [90]. The extracting solvent is immiscible with and less dense than water. Upon heating, volatile compounds in the steam are transferred to the solvent and both liquids condense. The glassware is constructed so that both solvent and water are returned to their starting vessels. After an extraction time of 1–12 h, the extract is collected and dried, either using anhydrous sodium sulfate, or by freezing and decanting the solvent from the ice. The extract is then concentrated before analysis to a volume of approximately 0.1 mL; a low-boiling extracting solvent is therefore desirable, so that it can be removed without substantial losses of compounds of interest. In addition, the solvent should be of high purity, so that impurities do not become major chromatographic peaks, when the extract is concentrated. Appropriate solvents, which have been widely used, are pentane, diethyl ether, or a combination of the two. Solvents denser than water, e.g., dichloromethane, could be used in a modified apparatus.

Numerous authors have used simultaneous distillation/extraction (SDE) at atmospheric pressure to analyze aroma compounds in fish and seafood. In particular, extraction using diethyl ether has been used to analyze carp [91], smoked salmon [53,54], krill [92,93], shrimp [62], clam [94], crab [95], fermented fish pastes [58], and fish sauce [71], while extraction using dichloromethane has been used to study turbot [24], mackerel [96], crab [77,97], scallops [98–100], mussels [101,102], squid [99], prawns [99,103], and phenolic compounds in smoked herring [52]. Morita et al. used SDE with dichloromethane to examine the volatile compositions of 16 different saltwater and freshwater fish species, including tuna, cod, carp, swordfish, mackerel, eel, and flounder [104]. SDE has been widely used for the analysis of bromophenols in fish and seafood. The extracted bromophenols have been usually analyzed by GC–MS [11,12,105–108], although high-performance liquid chromatography (HPLC) method with UV detection has also been developed [109].

SDE has several advantages to the other commonly used extraction techniques. Efficient stripping of volatiles from foods allows quantitative recoveries to be achieved for many

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

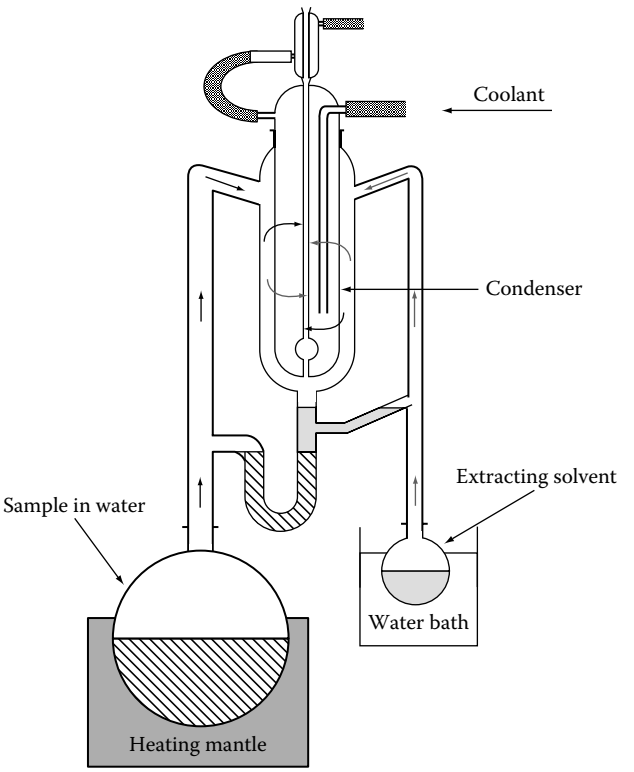


Figure 14.1 Likens–Nickerson apparatus for simultaneous steam distillation/extraction.

compounds [110]. The aroma extract is obtained in a solvent; therefore, many injections can be performed from one extraction. Hence, one sample could provide material for GC, GC–MS, and for quantitative GC–olfactometry (GC–O) techniques, such as AEDA [111]. Fractionation of the extract can be carried out, resulting in increased separation of the components in the extract, facilitating the identification of minor components. For example, Kubota et al. [112] separated the extract from cooked shrimps into neutral and basic fractions. The basic fraction was high in nitrogen-containing compounds, as these compounds become more water-soluble at high pH, due to protonation of the nitrogen. The neutral fraction contained mainly sulfur-containing compounds.

As with all aroma extraction techniques, SDE has drawbacks. When the extract is concentrated, by distilling off the solvent, low-boiling volatile compounds can be lost. These compounds include 2-butanone, 2-pentanone, 2- and 3-methylbutanal, diacetyl, 1-propanol, and 1-penten-3-ol, which are often present at high levels in headspace extracts of fish and seafood. Artifacts can be formed as a result of the high temperatures used. In addition, volatiles can be generated when samples are overcooked during extraction, e.g., through enhanced lipid oxidation [113].

If SDE is carried out under reduced pressure, thermal degradation of labile components can be diminished. By maintaining the system under a static vacuum, extraction at room temperature is possible. Vacuum SDE with dichloromethane has been used to examine lobster [4,114], blue crab [77], and tuna fish sauce [115]. An excellent discussion of SDE is available [110].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

14.4.4 High Vacuum Distillation/Solvent-Assisted Flavor Evaporation

Because SDE may lead to artifact formation and overcooking, a high vacuum transfer technique was developed in the early 1990s, as a way of removing the volatile aroma compounds from solvent extracts of food materials. A series of cold traps was used to collect the volatile material, after it had sublimed. This technique was shown to be more efficient than SDE for high-boiling polar compounds, such as furaneol. Dichloromethane at room temperature has been used to extract volatile compounds from ripening anchovy [116,117] and uncooked hake [32], while diethyl ether under reflux has been used for boiled trout [2] and carp [118].

There were numerous drawbacks with the technique and a robust alternative, known as solvent-assisted flavor evaporation (SAFE) was developed, to supersede it (Figure 14.2). Although high vacuum transfer and SAFE are similar techniques in principal, greater thermal control and a more compact arrangement of the glassware means that SAFE is more efficient than high vacuum transfer, resulting in higher yields of high-boiling and polar compounds [119]. It can also be used directly on the food, with no need of a solvent extraction step, producing an extract with typical aroma. Hence, the time of extract preparation can be substantially reduced.

No work on fish aroma using SAFE has so far been published.

14.4.5 Headspace Analysis

Commercial automated headspace analyzers are often used for routine analysis of volatile compounds. These allow temperature control of the sample and may include agitation. The headspace sample vial may be pressurized before injection, to improve reproducibility and increase sensitivity. Automated systems have been used for the analysis of sea bream [22], mackerel [36], canned pink salmon [38,39,44,120], and tuna [121]. However, manual headspace analysis was used to

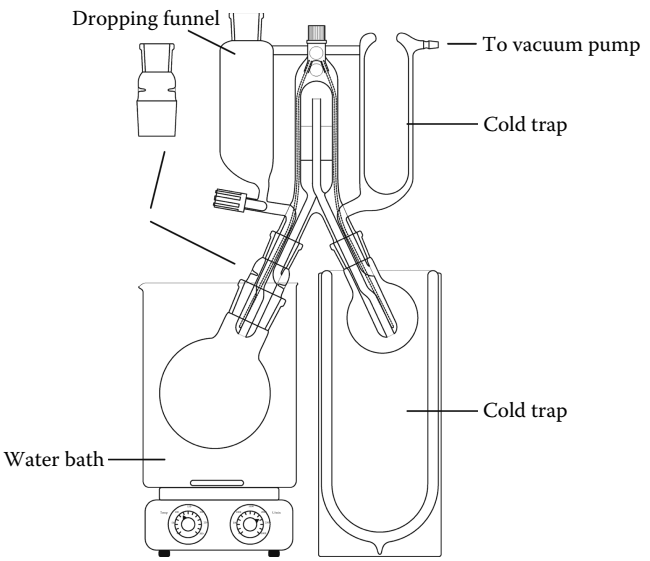


Figure 14.2 Solvent-assisted flavor evaporation apparatus.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

characterize the key aroma components of boiled salmon, cod, and trout [1–3], and those of salted-dried white herring [57].

A concentrated headspace extract can be obtained by passing a stream of inert gas (nitrogen or helium) over the sample and condensing the volatiles in a series of traps cooled by ice, solid carbon dioxide, or liquid nitrogen. Extraction of the condensate with a small amount of a suitable solvent provides an aroma extract suitable for chromatographic analysis. Alternatively, the condensed volatiles can be swept directly into the injection port of a gas chromatograph. The latter technique was used to examine spoilage in prawns and also to measure the low-boiling volatile compounds, hydrogen sulfide [41] and ethanol [42], in tuna. Ethanol was also measured in canned salmon, using a similar technique [122], although automated headspace analysis appears to be the most appropriate methodology for ethanol quantification [123,124]. Both hydrogen sulfide and ethanol are regarded as indicators of spoilage in fish [125]. Yasuhara and Shibamoto [126] trapped collected volatiles from nine species of seafood, including mackerel, red salmon, and squid, in a cysteamine solution, which converted the aldehydes present into thiazolidines. The thiazolidines were then extracted in dichloromethane and concentrated for analysis. This method was particularly useful for measuring formaldehyde and acetaldehyde, which are usually too volatile to be measured by conventional aroma analysis techniques.

The theory and practice of static headspace analysis have been well discussed [127].

14.4.6 Adsorption

Headspace aroma volatiles can also be collected on suitable adsorbent materials, the most widely used of which is Tenax TA, a porous polymer resin based on 2,6-diphenylene oxide. These materials readily adsorb volatiles while having little affinity for water, making them particularly useful in the analysis of samples with high water content.

In a typical collection, purified inert gas sweeps the volatiles from the sample flask into a small tube containing from 10 to 200 mg of the adsorbent (Figure 14.3), which is usually called a "trap." Typically at least five volumes of headspace should be collected from the sample vessel. Adsorbed volatiles can be heat desorbed directly onto a gas chromatographic column by placing the trap in a specially modified injection port, thus avoiding loss of components or unnecessary dilution.

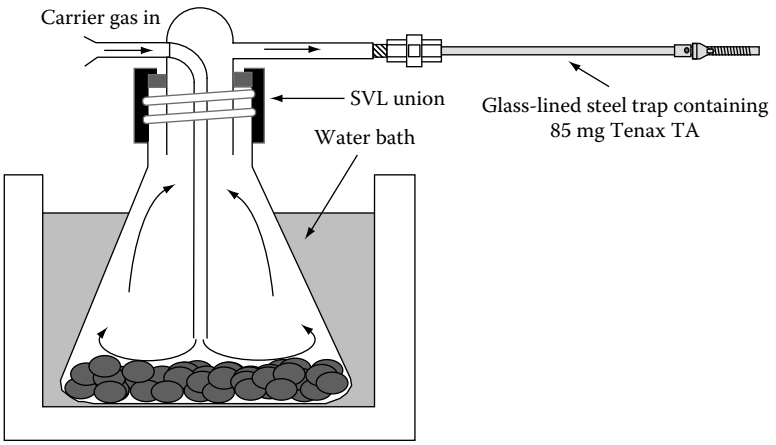


Figure 14.3 Headspace adsorption on Tenax TA.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Cooling the front of the column cryogenically or with Peltier cooling during this desorption will avoid any loss in chromatographic resolution.

Tenax TA has been use for the analysis of boiled crab [128], fresh smelt [129], fresh ayu [20], steamed clam [94], and fish sauce [69,72,73]. Forerunners of Tenax TA include Tenax GC, which has been used to analyze cooked salmon [21], roasted dried squid [130], and fresh and fermented shrimp [60]. The aromas of fresh and canned sea urchin gonads were compared by trapping on graphitized carbon black, followed by microwave desorption [43].

Solvent desorption, rather than heat desorption, from the trap with diethyl ether, followed by concentration, has been used to prepare aroma extracts of whitefish [131,132], smelt, perch, pike, rainbow trout, cod, sole, haddock [132], salmon [133], and oysters [134], using Tenax GC; and lobster with Tenax TA [4]. Ishizaki et al. collected shrimp volatiles on Tenax TA, using a pump, and then desorbed the trap with diethyl ether [135].

Automated devices exist for headspace adsorption, followed by thermal desorption in a dedicated injection port. These have been used to analyze raw sardine [35], canned salmon [40], cooked catfish [136–138], baked herring [139], raw oyster [86,140], pasteurized crab [141], and boiled crayfish [141,142]. Where samples have been extracted manually, multitrap autosamplers can be used to heat desorb the volatile compounds, allowing round-the-clock GC–MS analysis. Aroma volatiles in fresh [143,144], cooked [145], and smoked [143] salmon were measured using Tenax TA, followed by automated thermal desorption, as were fresh cod, saithe, mackerel, redfish [144], and ripened cod's roe [146], while the same apparatus with Tenax GR was used to examine salted herring during ripening [147] and off-flavor development in herring oil [148].

Headspace adsorption on Tenax is a desirable technique because it is sensitive, and extracts a wide boiling point range of volatile compounds; artifact formation is minimal, as extraction is carried out under inert gas flow. However, a dedicated injection system for traps may be expensive, especially if automated extraction is desired. Normally only one GC analysis is obtained from each extraction, unless solvents are used to desorb the contents of the traps.

14.4.7 Solid-Phase Microextraction

A very popular and simple to use technique, introduced in the early 1990s [149], solid-phase microextraction (SPME) uses a small fused silica fiber, coated in an adsorbent material, mounted inside a syringe-like device (Figure 14.4). The needle is pushed through a septum and the fiber is exposed to the headspace above the food or beverage sample, which is sealed in a suitable container. Volatile compounds are adsorbed onto the fiber and, at the end of the extraction, the fiber can be removed from the sample vessel and directly desorbed into the split/splitless injector of a gas chromatograph. The injector of the GC contains a very narrow quartz liner, which helps to focus the volatile compounds at the front of the GC column. Alternatively, cryofocusing of the aroma volatiles on the front of the column can be performed, to prevent peak broadening. SPME can be automated and its ease of use, relatively low cost, and affinity for a large range of compounds has meant that it has become a widely used technique for the isolation of aroma volatiles [150].

Numerous different stationary phases have been used as coatings for SPME fibers. Coatings may be absorptive—volatiles are bound to the surface of the fiber, or adsorptive—volatiles are trapped within pores in the stationary phase [151]. Popular absorptive phases include polydimethylsiloxane (PDMS), while Carboxen and divinylbenzene (DVB) are adsorptive phases. Fibers containing a mixture of stationary phases are commonly used.

Virtually every available type of SPME fiber has been used for the analysis of fish, and several workers have compared the performances of two or more fibers. A PDMS fiber was used to

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

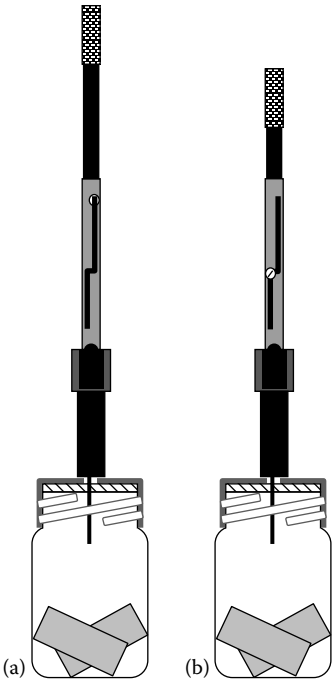


Figure 14.4 Solid phase microextraction: (a) fiber inside syringe barrel; and (b) fiber exposed during extraction.

examine the effects of storage on yellowfin tuna [29], while a polyacrylate fiber was found to be most suitable for comparing smoked with unsmoked black bream and rainbow trout [48], and also for analyzing smoked cod and swordfish [49]. Using a PDMS/DVB fiber, Song et al. [152] discovered that the aroma of uncooked hepatic tissue was stronger than that of uncooked muscle for carp, flounder, mackerel, and skipjack. Both a PDMS/DVB fiber and a PDMS fiber were used to examine the aroma of fresh scallops [153], while DVB/Carboxen/PDMS fibers have been used to examine sardine freshness [33,34]. Carboxen/PDMS fibers have been used to monitor king salmon [28], whiting, cod, and mackerel spoilage [26], and measure aroma compounds in sea bream, chum salmon, mackerel, sardine, tuna, prawn, and shrimp [154].

Using the technique known as in-fiber derivatization, low-molecular weight aldehydes were measured in raw pollock by SPME [155]. The aldehydes in the fish reacted with the stationary phase of the fiber, to give a derivative, which, in the case of formaldehyde and acetaldehyde, was more amenable to GC–MS analysis than their underivatized equivalents. In-fiber derivatization has also been used to measure formaldehyde in 12 fish species, including cod, haddock, tuna, and trout [156].

Like headspace adsorption on Tenax, SPME is a desirable technique because it is sensitive, and extracts a wide boiling point range of volatile compound. Again artifact formation is minimal. Its big advantage over headspace adsorption is that it can be used with any GC. It is also the easiest aroma extraction technique to use, requiring little training. Method development is straightforward and a choice of stationary phases means that the extraction can be tailored, in order to maximize extraction of desired compounds. Like headspace adsorption with thermal desorption, only one GC analysis is obtained from each extraction.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

14.4.8 Analysis of Trimethylamine Oxide Breakdown Products

As stated earlier in the chapter, TMA measurement is regularly used to monitor spoilage, and TMA is often reported as a component of fish aroma. For example, Chung and Cadwallader [5] reported that TMA gave a fishy note to boiled crab aroma, while Milo and Grosch [10] reported that TMA gave an amine-like aroma to cod, which increased during frozen storage. TMA and other TMAO-breakdown products are often measured alone, to provide an indicator of fish freshness, using techniques that are not appropriate for the analysis of other aroma compounds. These techniques will be described in a later chapter.

Several workers have used SPME to analyze volatile amines. Chan et al. [157] used a Carboxen/DVB/PDMS fiber for the extraction of volatile amines from homogenized fillets of mangrove snapper and freshwater grouper. Li et al. [158] used an amine-selective SPME fiber to study TMA levels in ground chub fillet stored under different conditions.

14.4.9 Analysis of Geosmin and 2-Methylisoborneol

2-Methylisoborneol and geosmin have extremely low odor thresholds [159], which impart undesirable tastes and odors in fish; catfish suffers in particular from problems caused by these two compounds. Although both compounds can be identified in fish using the techniques applicable to volatile aroma compounds in general (SDE [160]; solvent extraction [161]; headspace adsorption [21]; SPME [162]), procedures have been developed specifically for the accurate quantification of methylisoborneol and geosmin. Microwave distillation, a form of steam distillation, has been used as an effective means of quantitatively extracting methylisoborneol and geosmin from the fish matrix [163,164], as has vacuum distillation [165]. The aqueous extract that results can then be extracted further, using SPME [163,166], solid-phase extraction [164], or trapping on an adsorbent [165].

14.5 Separation and Identification of Aroma Components

To determine the important compounds in an aroma extract, the complex mixture needs to be separated into its components. The amount of isolate is usually small, containing many compounds of diverse chemical structures, varying greatly in concentration, and important components are often present in extremely low amounts. The success of any aroma analysis depends mainly upon the efficiency of separation and the sensitivity of detection. GC using bonded phase fused silica capillary columns is universally used as the separation method in aroma analysis. Such columns can separate complex mixtures, and the most commonly used stationary phases are Carbowax 20 M, a polar phase, and the two nonpolar phases, 100% poly(dimethylsiloxane) and poly(5% diphenylsiloxane/95% dimethylsiloxane). The retention times of an aroma compound on two columns with different stationary phases, relative to the retention times of a series of straight-chain alkanes can be helpful in its identification; databases containing retention data for volatile compounds are available [167]. GC is a widely used technique and will not be discussed here.

Structure elucidation of the chromatographically separated components is the next step in the analysis of an aroma isolate. GC–MS allows direct analysis of the separated components and provides the most efficient means of volatile identification. Compounds eluting from the GC column enter the ion source of the mass spectrometer, where they are ionized and break into fragments. The fragments are separated by their mass-to-charge ratio, resulting in a characteristic spectrum, which will provide structural information.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Several types of mass spectrometer are suitable for the identification of aroma compounds, although most of the work discussed in this chapter was performed using single quadrupole mass spectrometers. Although single quadrupoles are by far the most common type of mass spectrometer for GC–MS, other types of mass spectrometer are used [168]. Ion traps and triple quadrupoles offer all of the capabilities of the single quadrupole, plus MS–MS, i.e., the trapping of fragments from the first ionization, for further fragmentation, in order to yield more structural information about unknown compounds. Double-focusing magnetic sector mass spectrometers can acquire accurate mass data, allowing the calculation of the empirical formula of an unknown compound. These machines are relatively expensive compared to quadrupoles and less robust, so are used far less often for routine flavor analysis.

Time-of-flight (TOF) machines have become increasingly popular as mass spectrometric detectors, with newer models offering rapid scan speeds (up to 500 spectra per second) and accurate mass measurement. High scan speeds are necessary when using fast GC techniques, such as two-dimensional GC (GC × GC), where small time-window fractions are diverted from the first analytical column, onto a second short column with a different stationary phase to the first column [169]. Rapid elution of the peaks from the second column (6 s maximum), allow a two-dimensional trace to be obtained. TOF machines are robust but relatively expensive, although, as they have been introduced relatively recently, they may become cheaper as they become more popular [170].

The characterization of unknown compounds is greatly facilitated by comparing their mass spectra with those of known compounds in compiled libraries, which are supplied with the GC–MS data system. Confirmation of the identity of compounds should always be carried out, preferably by comparing their mass spectra and GC retention times with those of authentic samples.

14.6 Quantification of Aroma Components

Often quantitative information on aroma compounds in a food is needed, for example, when using AEDA to determine the key compounds contributing to the aroma of a food. Quantification is rarely simple, because most extraction techniques only remove a proportion of the aroma from the food, and difficulties may arise when compounds are not resolved by GC.

The most effective means of quantification is isotope dilution assay using GC–MS. A known amount of a ^{13}C- or ^{2}H-labeled internal standard is added to a slurry of the food under study, in order to quantify its nonlabeled equivalent. As the labeled and unlabeled aroma compound possess similar physical properties, the proportion of each extracted from the food will be the same. The relationship between the mass spectral peaks of the labeled standard and the compound of interest can be used to calculate accurately the amount of the compound of interest in the food. If the labeled standard is homogeneously distributed within the food, then quantitative extraction of the compound under study is not necessary [171].

Other quantification methods include the addition of an internal standard, not present in the food, of a similar chemical composition to the compound of interest, e.g., 2-methylpentanal could be used to quantify hexanal. Alternatively, one added compound can be used to approximately quantify all of the compounds in an extract, by measuring their peak areas relative to that of the added compound. 2,4,6-Trimethylpyridine, *p*-cymene, and ethyl heptanoate are compounds, which have been used several times for this purpose, in the analysis of fish and seafood. If the extraction of the compound of interest is quantitative, then solutions of the compound of interest

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

can be used to plot a calibration curve (an external standard), which can then be used to quantify that compound. Lee et al., using vacuum SDE, extracted standard compounds at a series of concentrations under the same conditions as the sample, in order to accurately quantify selected compounds in lobster tail meat [114].

Conversely, standards could be added to the extract. The peak area of a known concentration of a standard added to an extract can be compared with the peak areas of all the compounds in the extract, to give an approximate concentration for all of the compounds in the extract. Standards can be injected into traps containing adsorbent and, in the case of SPME, injected onto the GC column immediately before desorption of the fiber. Methanol is a useful solvent for such standards; it can be easily purged from the trap as its affinity for Tenax is very low and as its molecular weight is 32, data acquisition down to *m/z* 33 will provide enough mass spectral data for successful library searching, without peaks of interest being hidden by a solvent peak.

14.7 Detection of Components of Sensory Significance

A widely used technique for determining components that contribute to aroma is GC–O. The column effluent is split between a conventional GC detector and a vent to the outside of the oven, where the odors emerging can be smelled and described [172].

AEDA is a quantitative GC–O technique, which has been used many times to estimate the relative contributions of volatile components toward the total aroma quality of cooked fish and seafood. The aroma extract under study is diluted twofold and analyzed by GC–O, then diluted twofold again and again. After a certain number of dilutions of the extract, no aromas will be perceived. The flavor dilution factor for a particular compound is defined as the highest dilution at which that compound can be perceived by GC–O. For example, if the concentration of the extract was halved at each dilution and the seventh dilution was the last at which the compound could be detected, its flavor dilution factor would be 2^7 (128). Hence, if the aroma extract is representative of the food from which it is derived, the most important contributors to the aroma of the food are those with the highest flavor dilution factors. It should be noted that components with high flavor dilution factors might not give GC peaks of any significant size. These flavor dilution factors can be plotted against retention time, to give an aromagram for a particular extract. When combined with isotope dilution analysis, AEDA is a very powerful technique for the identification of the key compounds in fish flavor [1,2]. Other quantitative GC–O techniques, such as CHARM analysis, olfactory global analysis, and OSME, have also been used for the analysis of fish aroma [101,173].

GC–O has shown that, for many raw and cooked fish and shellfish, lipid-derived compounds, such as unsaturated aldehydes, alcohols, and ketones, are character-impact compounds, while methional, dimethyl disulfide, 2-acetyl-1-pyrroline, 3-methylbutanal, and alkylpyrazines are important compounds formed in cooked fish, *via* the Maillard reaction.

As well as the use of GC–O, several papers have been published on fish aroma, which combine aroma extraction with sensory analysis. Varlet et al. [54] extracted aroma from smoked salmon, then added the extract to unsmoked salmon, to be analyzed by a trained panel, in order to examine the representativeness of the aroma extraction method used (SDE). Morita et al. [104] prepared fish broths from 16 species, and related compounds in these broths with sensory attributes. The 16 species were divided into four groups, associated with particular aroma notes, which could be correlated with certain aroma compounds.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

14.8 The Electronic Nose

Originally, the term "electronic nose" was used to describe an array of chemical sensors, connected to a pattern recognition system, which responded to odors passing over it. Different odors cause different responses in the sensors and these responses provide a signal pattern, characteristic of a particular aroma. The computer evaluates the signal pattern and can compare the aromas of different samples, using pattern recognition. Sensors are usually made of metal oxides or organic polymers, although more recently surface acoustic waves and piezoelectric crystals have been used. Problems may exist when samples with a high water content are analyzed, as many of the sensors respond strongly toward water, preventing any sample differences being observed.

Electronic noses have been widely used in fish aroma analysis, particularly with regard to fish freshness. Olafsdottir et al. used four gas-specific sensors, for CO, NH_3, H_2S, and SO_2, to measure quality changes in stored cod, and related results to volatile formation (particularly ethanol and 2-methyl-1-propanol), pH change, and microbial spoilage [27]. Du et al. used an electronic nose with polymer sensors and a sensory panel to examine quality changes during storage of yellowfin tuna [174]. Jonsdottir et al. showed a good correlation between sensory results, electronic nose data, and aroma compound formation in stored, ripened cod's roe [146].

More recently, electronic noses based on MS have been developed, which are also known as mass sensors or MS-noses. Volatile compounds are introduced directly into the mass spectrometer, without any preseparation. With these instruments, each mass scanned by the mass spectrometer can be described as a sensor, which detects any ion fragment with that mass. In fact, the mass sensor is taking all of the scans that make up a GC–MS run and then combining these scans, to provide a fingerprint of the food under study. The advantages of these machines over conventional electronic noses are that they are less prone to sensor poisoning (due to excess sample), moisture effects, and nonlinearity of signals [175]. This technique has been used to measure spoilage volatiles in the headspace of whiting, cod, and mackerel [26]. A related technique involves conventional GC–MS, followed by summing of all the spectral data to give an MS fingerprint. Slurries of fresh oysters were extracted by SPME, followed by GC–MS. Mass fragments that were shown to vary between treatments were then analyzed by a chemometric method. Five mass fragments were sufficient to completely discriminate oysters from seven production areas [176].

14.9 Future Developments

Since the mid-1990s, it has been possible to measure the release of aroma volatiles from chewed food in real time, using MS. As many volatile compounds enter the mass spectrometer at the same time, a soft ionization technique is used, i.e., one that favors the formation of a protonated molecular ion, with little additional fragmentation. The two processes most commonly used to achieve this are atmospheric pressure chemical ionization MS (APCI-MS) [177] and proton-transfer reaction MS (PTR-MS) [178]. A plastic tube is inserted into one nostril and exhaled air passes directly into the mass spectrometer, giving a characteristic sigmoid trace, with troughs during inhalation and peaks during exhalation.

The recent paper by Rochat et al. [179] showed the potential of two-dimensional GC, hyphenated to a TOF MS, as an unrivaled technique for the separation of complex mixtures. The technique is extremely sensitive, as a result of low background and exceptionally high peak resolution, allowing thousands of peaks to be separated in one GC–MS trace. At present, the cost of such equipment may place it beyond the reach of most analytical laboratories, but its potential is clear to see.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

SAFE would appear to be the most effective aroma extraction technique currently available; yields are higher than any other technique and sample degradation does not occur readily. Its potential has been shown in the analysis of numerous foods.

None of the three techniques described in this section have been used to analyze fish aroma so far, although their potential is clear. Even so, many of the other techniques described in this chapter will continue to be used for the foreseeable future.

References

1. Milo, C. and Grosch, W., Changes in the odorants of boiled salmon and cod as affected by the storage of the raw material, *J. Agric. Food Chem*., 44, 2366, 1996.
2. Milo, C. and Grosch, W., Changes in the odorants of boiled trout (*Salmo fario*) as affected by the storage of the raw material, *J. Agric. Food Chem*., 41, 2076, 1993.
3. Milo, C. and Grosch, W., Potent odorants in boiled cod as affected by the storage of raw material, in *Flavor and Lipid Chemistry of Seafoods*, Shahidi, F. and Cadwallader, K.R., Eds., American Chemical Society, Washington, DC, 1997, p. 110.
4. Cadwallader, K.R. et al., Evaluation of the aroma of cooked spiny lobster tail meat by aroma extract dilution analysis, *J. Agric. Food Chem*., 43, 2432, 1995.
5. Chung, H.Y. and Cadwallader, K.R., Aroma extract dilution analysis of blue-crab claw meat volatiles, *J. Agric. Food Chem*., 42, 2867, 1994.
6. Baek, H.H. and Cadwallader, K.R., Character-impact aroma compounds of crustaceans, in *Flavor and Lipid Chemistry of Seafoods*, Shahidi, F. and Cadwallader, K.R., Eds., American Chemical Society, Washington, DC, 1997, p. 85.
7. Cadwallader, K.R. and Baek H.H., Aroma-impact compounds in cooked tail meat of freshwater crayfish (*Procambarus clarkii*), in *Food Flavors: Formation, Analysis and Packaging Influences*, Contis, E.T. et al., Eds., Elsevier Science B.V., Amsterdam, the Netherlands, 1998, p. 271.
8. Durnford, E. and Shahidi, F., Flavour of fish meat, in *Flavor of Meat, Meat Products and Seafoods*, Shahidi, F., Ed., Blackie Academic and Professional, Glasgow, U.K., 1998, p. 131.
9. Krzymien, M.E. and Elias, L., Feasibility study on the determination of fish freshness by trimethylamine headspace analysis, *J. Food Sci*., 55, 1228, 1990.
10. Milo, C. and Grosch, W., Detection of odor defects in boiled cod and trout by gas-chromatography olfactometry of headspace samples, *J. Agric. Food Chem*., 43, 459, 1995.
11. Whitfield, F.B., Biological origins of off-flavors in fish and crustaceans, *Water Sci. Technol*., 40, 265, 1999.
12. Whitfield, F.B. et al., Distribution of bromophenols in Australian wild-harvested and cultivated prawns (shrimp), *J. Agric. Food Chem*., 45, 4398, 1997.
13. Serot, T. et al., Effect of dietary lipid sources on odour-active compounds in muscle of turbot (*Psetta maxima*), *J. Sci. Food Agric*., 81, 1339, 2001.
14. Serot, T., Regost, C., and Arzel, J., Identification of odour-active compounds in muscle of brown trout (*Salmo trutta*) as affected by dietary lipid sources, *J. Sci. Food Agric*., 82, 636, 2002.
15. Turchini, G.M. et al., Effects of dietary lipid sources on flavour volatile compounds of brown trout (*Salmo trutta* L.) fillet, *J. Appl. Ichthyol*., 20, 71, 2004.
16. Turchini, G.M. et al., Effects of dietary lipid source on fillet chemical composition, flavour volatile compounds and sensory characteristics in the freshwater fish tench (*Tinca tinca* L.), *Food Chem*., 102, 1144, 2007.
17. Runge, G. et al., Amounts of volatile sulfur-compounds in the edible part of carp (*Cyprinus carpio* L.) fed different fat and α-tocopheryl acetate dietary supplements, *Agribiol. Res*., 43, 183, 1990.
18. Pennarun, A.L. et al., Comparison of two microalgal diets. 2. Influence on odorant composition and organoleptic qualities of raw oysters (*Crassostrea gigas*), *J. Agric. Food Chem*., 51, 2011, 2003.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

19. Kin, J.-S., Ma, W.C.J., and Chung Y.H., Enhancement of bromophenol content in cultivated green grouper (*Epinephelus coloides*), *J. Fisheries Sci. Technol*., 10, 113, 2007.
20. Hirano, T. et al., Studies on the odor of fishes.1. Identification of volatile compounds in ayu fish and its feeds, *Nippon Suisan Gakkaishi*, 58, 547, 1992.
21. Farmer, L.J. et al., Flavor and off-flavor in wild and farmed Atlantic salmon from locations around Northern Ireland, *Water Sci. Technol*., 31, 259, 1995.
22. Grigorakis, K., Taylor, K.D.A., and Alexis, M.N., Organoleptic and volatile aroma compounds comparison of wild and cultured gilthead sea bream (*Sparus aurata*): Sensory differences and possible chemical basis, *Aquaculture*, 225, 109, 2003.
23. Alasalvar, C., Taylor, K.D.A., and Shahidi, F., Comparison of volatiles of cultured and wild sea bream (*Sparus aurata*) during storage in ice by dynamic headspace analysis gas chromatography mass spectrometry, *J. Agric. Food Chem*., 53, 2616, 2005.
24. Prost, C., Serot, T., and Demaimay, M., Identification of the most potent odorants in wild and farmed cooked turbot (*Scophtalamus maximus* L.), *J. Agric. Food Chem*., 46, 3214, 1998.
25. Turchini, G.M. et al., Discrimination of origin of farmed trout by means of biometrical parameters, fillet composition and flavor volatile compounds, *Ital. J. Anim. Sci*., 3, 123, 2004.
26. Duflos, G. et al., Determination of volatile compounds to characterize fish spoilage using headspace/mass spectrometry and solid-phase microextraction/gas chromatography/mass spectrometry, *J. Sci. Food Agric*., 86, 600–611, 2006.
27. Olafsdottir, G. et al., Characterization of volatile compounds in chilled cod (*Gadus morhua*) fillets by gas chromatography and detection of quality indicators by an electronic nose, *J. Agric. Food Chem*., 53, 10140, 2005.
28. Wierda, R.L. et al., Analysis of volatile compounds as spoilage indicators in fresh king salmon (*Oncorhynchus tshawytscha*) during storage using SPME-GC-MS, *J. Agric. Food Chem*., 54, 8480, 2006.
29. Edirisinghe, R.K.B., Graham, A.J., and Taylor, S.J., Characterisation of the volatiles of yellowfin tuna (*Thunnus albacares*) during storage by solid phase microextraction and GC-MS and their relationship to fish quality parameters, *Int. J. Food Sci. Technol*., 42, 1139, 2007.
30. Josephson, D.B., Lindsay, R.C., and Stuiber, D.A., Identification of volatile aroma compounds from oxidized frozen whitefish (*Coregonus clupeaformis*), *Can. Inst. Food Sci. Technol. J*., 17, 178, 1984.
31. Choi, S.H. and Kato, H., Odor of fermented small shrimp. 4. Changes in cooked odor of Antarctic krill during frozen storage, *Agric. Biol. Chem*., 48, 545, 1984.
32. Triqui, R., Sensory and flavor profiles as a means of assessing freshness of hake (*Merluccius merluccius*) during ice storage, *Eur. Food Res Technol*., 222, 41, 2006.
33. Triqui, R. and Bouchriti, N., Freshness assessments of Moroccan sardine (*Sardina pilchardus*): Comparison of overall sensory changes to instrumentally determined volatiles, *J. Agric. Food Chem*., 51, 7540, 2003.
34. Ganeko, N. et al., Analysis of volatile flavor compounds of sardine (*Sardinops melanostica*) by solid phase microextraction, *J. Food Sci*., 73, S83, 2008.
35. Prost, C. et al., Effect of storage time on raw sardine (*Sardina pilchardus*) flavor and aroma quality, *J. Food Sci*., 69, S198, 2004.
36. Alasalvar, C., Quantick, P.C., and Grigor, J.M., Aroma compounds of fresh and stored mackerel (*Scomber scombrus*), in *Flavor and Lipid Chemistry of Seafoods*, Shahidi, F. and Cadwallader, K.R., Eds., American Chemical Society, Washington, DC, 1997, p. 39.
37. Frankel, E.N., Formation of headspace volatiles by thermal-decomposition of oxidized fish oils vs oxidized vegetable oils, *J. Am. Oil Chem. Soc*., 70, 767, 1993.
38. Girard, B. and Nakai, S., Static headspace gas chromatographic method for volatiles in canned salmon, *J. Food Sci*., 56, 1271, 1991.
39. Girard, B. and Nakai, S., Grade classification of canned pink salmon with static headspace volatile patterns, *J. Food Sci*., 59, 507, 1994.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

40. Girard, B. and Durance, T., Headspace volatiles of sockeye and pink salmon as affected by retort process, *J. Food Sci.*, 65, 34, 2000.
41. Khayat, A., Hydrogen sulfide production by heating tuna meat, *J. Food Sci.*, 42, 601, 1977.
42. Lerke, P.A. and Huck, R.W., Objective determination of canned tuna quality—Identification of ethanol as a potentially useful index, *J. Food Sci.*, 42, 755, 1977.
43. De Quiros, A.R.B. et al., Comparison of volatile components in fresh and canned sea urchin (*Paracentrotus lividus*, Lamarck) gonads by GC-MS using dynamic headspace sampling and microwave desorption, *Eur. Food Res. Technol.*, 212, 643, 2001.
44. Oliveira, A.C.M. et al., Headspace gas chromatography-mass spectrometry and electronic nose analysis of volatile compounds in canned Alaska pink salmon having various grades of watermarking, *J. Food Sci.*, 70, S419, 2005.
45. Przybylski, R., Eskin, N.A.M., and Malcolmson, L.J., Development of a gas chromatographic system for trapping and analyzing volatiles from canned tuna, *Can. Inst. Sci. Technol. J.*, 24, 129, 1991.
46. Cardinal, M. et al., Effects of the smoking process on odour characteristics of smoked herring (*Clupea harengus*) and relationships with phenolic compound content, *Food Chem.*, 96, 137, 2006.
47. Cardinal, M. et al., Effect of various smoking techniques on the nature of volatile compounds and on the sensory characteristics of salmon meat, *Sci. Aliments*, 17, 679, 1997.
48. Guillen, M.D. and Errecalde, M.C., Volatile components of raw and smoked black bream (*Brama raii*) and rainbow trout (*Oncorhynchus mykiss*) studied by means of solid phase microextraction and gas chromatography/mass spectrometry, *J. Sci. Food Agric.*, 82, 945, 2002.
49. Guillen, M.D. et al., Headspace volatile components of smoked swordfish (*Xiphias gladius*) and cod (*Gadus morhua*) detected by means of solid phase microextraction and gas chromatography-mass spectrometry, *Food Chem.*, 94, 151, 2006.
50. Ishiguro, K., Wakabayashi, H., and Kawaguchi, H., Changes in volatile compounds during smoking process and evaluation of major aroma constituents of dried bonito (*Katuo bushi*), *J. Jpn. Soc. Food Sci. Technol.*, 48, 570, 2001.
51. Sakakibara, H. et al., Volatile flavor compounds of some kinds of dried and smoked fish, *Agric. Biol. Chem.*, 54, 9, 1990.
52. Serot, T. et al., Effect of smoking processes on the contents of 10 major phenolic compounds in smoked fillets of herring (*Cuplea harengus*), *Food Chem.*, 85, 111, 2004.
53. Varlet, V. et al., Olfactometric determination of the most potent odor-active compounds in salmon muscle (*Salmo salar*) smoked by using four smoke generation techniques, *J. Agric. Food Chem.*, 55, 4518, 2007.
54. Varlet, V., Prost, C., and Serot, T., New procedure for the study of odour representativeness of aromatic extracts from smoked salmon, *Food Chem.*, 100, 820, 2007.
55. Varlet, V., Prost, C., and Serot, T., Volatile aldehydes in smoked fish: Analysis methods, occurrence and mechanisms of formation, *Food Chem.*, 105, 1536, 2007.
56. Varlet, V. et al., Comparison of odor-active volatile compounds of fresh and smoked salmon, *J. Agric. Food Chem.*, 54, 3391, 2006.
57. Chung, H.Y. et al., Static headspace analysis-olfactometry (SHA-O) of odor impact components in salted-dried white herring (*Ilisha elongata*), *Food Chem.*, 104, 842, 2007.
58. Cha, Y.J. and Cadwallader, K.R., Volatile components in salt-fermented fish and shrimp pastes, *J. Food Sci.*, 60, 19, 1995.
59. Cha, Y.J., Lee, G.H., and Cadwallader, K.R., Aroma-active compounds in salt-fermented anchovy, in *Flavor and Lipid Chemistry of Seafoods*, Shahidi, F. and Cadwallader, K.R., Eds., American Chemical Society, Washington, DC, 1997, p. 131.
60. Choi, S.H. and Kato, H., Odor of fermented small shrimp. 5. Volatile components of *Sergia lucens* and its fermented product, *Agric. Biol. Chem.*, 48, 1479, 1984.
61. Choi, S.H. and Kobayashi, A., Odor of fermented small shrimp. 2. Cooked odor of commercial shiokara made from mysid shrimps, *J. Jpn. Soc. Food Sci. Technol.*, 30, 404, 1983.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

62. Choi, S.H., Kobayashi, A., and Yamanishi, T., Odor of fermented small shrimp. 1. Odor of cooked small shrimp, *Acetes Japonicus* Kishinouye—Difference between raw-material and fermented product, *Agric. Biol. Chem*., 47, 337, 1983.
63. Choi, S.H. and Kato, H., Odor of fermented small shrimp. 6. Flavor of fermented product of Antarctic krill prepared by modified method, *J. Jpn. Soc. Food Sci. Technol*., 32, 274, 1985.
64. Nordvi, B. et al., Characterization of volatile compounds in a fermented and dried fish product during cold storage, *J. Food Sci*., 72, S373, 2007.
65. Chung, H.Y. et al., Analysis of volatile components in frozen and dried scallops (*Patinopecten yessoensis*) by gas chromatography/mass spectrometry, *Food Res. Int*., 35, 43, 2002.
66. Josephson, D.B., Lindsay, R.C., and Stuiber, D.A., Influence of processing on the volatile compounds characterizing the flavor of pickled fish, *J. Food Sci*., 52, 10, 1987.
67. Sharma, S.K., Basu, S., and Gholap, A.S., Effect of irradiation on the volatile compounds of shrimp (*Solenocera choprii*), *J. Food Sci. Technol. Mysore*, 44, 267, 2007.
68. Lopetcharat, K. et al., Fish sauce products and manufacturing: A review, *Food Rev. Int*., 17, 65, 2001.
69. Fukami, K. et al., Identification of distinctive volatile compounds in fish sauce, *J. Agric. Food Chem*., 50, 5412, 2002.
70. McIver, R.C., Brooks, R.I., and Reineccius, G.A., Flavor of fermented fish sauce, *J. Agric. Food Chem*., 30, 1017, 1982.
71. Peralta, R.R., Shimoda, M., and Osajima, Y., Further identification of volatile compounds in fish sauce, *J. Agric. Food Chem*., 44, 3606, 1996.
72. Shimoda, M., Peralta, R.R., and Osajima, Y., Headspace gas analysis of fish sauce, *J. Agric. Food Chem*., 44, 3601, 1996.
73. Michihata, T., Yano, T., and Enomoto, T., Volatile compounds of headspace gas in the Japanese fish sauce *Ishiru*, *Biosci. Biotech. Biochem*., 66, 2251, 2002.
74. Cha, Y.J., Baek, H.H., and Hsieh, T.C.Y., Volatile components in flavor concentrates from crayfish processing waste, *J. Sci. Food Agric*., 58, 239, 1992.
75. Cha, Y.J., Cadwallader, K.R., and Baek, H.H., Volatile flavor components in snow crab cooker effluent and effluent concentrate, *J. Food Sci*., 58, 525, 1993.
76. Tanchotikul, U. and Hsieh, T.C.Y., Volatile flavor components in crayfish waste, *J. Food Sci*., 54, 1515, 1989.
77. Elmore, J.S., Aroma, in *Handbook of Muscle Foods Analysis*, Nollet, L.M.L. and Toldrá, F., Eds., Taylor & Francis, Boca Raton, FL, 2008.
78. Chung, H.Y. and Cadwallader, K.R., Volatile components in blue-crab (*Callinectes sapidus*) meat and processing by-product, *J. Food Sci*., 58, 1203, 1993.
79. Aro, T. et al., Determination of semivolatile compounds in Baltic herring (*Clupea harengus membras*) by supercritical fluid extraction-supercritical fluid chromatography-gas chromatography-mass spectrometry, *J. Agric. Food Chem*., 50, 1970, 2002.
80. Roh, H.S. et al., Isolation of off-flavors and odors from tuna fish oil using supercritical carbon dioxide, *Biotech. Bioprocess Eng*., 11, 496, 2006.
81. Kubota, K. et al., Odor of Antarctic krills. Part 1. Cooked odor of Antarctic krills, *J. Agric. Chem. Soc. Jpn*., 54, 1, 1980.
82. Shen, C., Xie, J., and Xu, X.S., The components of cuttlefish (*Sepiella maindroni de Rochebruns*) oil, *Food Chem*., 102, 210, 2007.
83. Triqui, R. and Reineccius, G.A., Flavor development in the ripening of anchovy (*Engraulis encrasicholus* L.), *J. Agric. Food Chem*., 43, 453, 1995.
84. Triqui, R. and Reineccius, G.A., Changes in flavor profiles with ripening of anchovy (*Engraulis encrasicholus*), *J. Agric. Food Chem*., 43, 1883, 1995.
85. Pennarun, A.L., Prost, C., and Demaimay, M., Identification and origin of the character-impact compounds of raw oyster *Crassostrea gigas*, *J. Sci. Food Agric*., 82, 1652, 2002.
86. Pennarun, A.L., Prost, C., and Demaimay, M., Aroma extracts from oyster *Crassostrea gigas*: Comparison of two extraction methods, *J. Agric. Food Chem*., 50, 299, 2002.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

87. Selli, S. et al., Characterization of aroma-active compounds in rainbow trout (*Oncorhynchus mykiss*) eliciting an off-odor, *J. Agric. Food Chem*., 54, 9496, 2006.
88. Le Guen, S., Prost, C., and Demaimay, M., Characterization of odorant compounds of mussels (*Mytilus edulis*) according to their origin using gas chromatography-olfactometry and gas chromatography-mass spectrometry, *J. Chromatogr. A*, 896, 361, 2000.
89. Le Guen, S., Prost, C., and Demaimay, M., Evaluation of the representativeness of the odor of cooked mussel extracts and the relationship between sensory descriptors and potent odorants, *J. Agric. Food Chem*., 49, 1321, 2001.
90. Likens, S.T. and Nickerson, G.B., Detection of certain hop oil constituents in brewing products, *Proc. Am. Soc. Brew. Chem*., 5, 1964.
91. Runge, G. and Steinhart, H., Determination of volatile sulfur-compounds in the edible part of carp, *Agribiol. Res*., 43, 155, 1990.
92. Kubota, K., Kobayashi, A., and Yamanishi, T., Cooked odor of Antarctic krills. 3. Some sulfur-containing compounds in cooked odor concentrate from boiled Antarctic krills (*Euphausia superba Dana*), *Agric. Biol. Chem*., 44, 2677, 1980.
93. Kubota, K., Kobayashi, A., and Yamanishi, T., Cooked odor of Antarctic krills. 6. Basic and neutral compounds in the cooked odor from Antarctic krill, *Agric. Biol. Chem*., 46, 2835, 1982.
94. Tanchotikul, U. and Hsieh, T.C.Y., Analysis of volatile flavor components in steamed Rangia clam by dynamic headspace sampling and simultaneous distillation and extraction, *J. Food Sci*., 56, 327, 1991.
95. Chen, D.W. and Zhang, M., Analysis of volatile compounds in Chinese Mitten Crab (*Eriocheir sinensis*), *J. Food Drug Anal*., 14, 297, 2006.
96. Zhang, H.Z. and Lee, T.C., Gas chromatography–mass spectrometry analysis of volatile flavor compounds in mackerel for assessment of fish quality, in *Flavor and Lipid Chemistry of Seafoods*, Shahidi, F. and Cadwallader, K.R., Eds., American Chemical Society, Washington, DC, 1997, p. 55.
97. Chung, H.Y., Volatile components in crabmeats of *Charybdis feriatus*, *J. Agric. Food Chem*., 47, 2280, 1999.
98. Chung, H.Y., Yung, I.K.S., and Kim, J.S., Comparison of volatile components in dried scallops (*Chlamys farreri* and *Patinopecten yessoensis*) prepared by boiling and steaming methods, *J. Agric. Food Chem*., 49, 192, 2001.
99. Morita, K., Kubota, K., and Aishima, T., Comparing sensory and gas chromatographic profiles in aromas of boiled squid, prawn, and scallop using full factorial design, *J. Food Sci*., 67, 3456, 2002.
100. Morita, K., Kubota, K., and Aishima, T., Investigating sensory characteristics and volatile components in boiled scallop aroma using chemometric techniques, *Food Chem*., 78, 39, 2002.
101. Le Guen, S., Prost, C., and Demaimay, M., Critical comparison of three olfactometric methods for the identification of the most potent odorants in cooked mussels (*Mytilus edulis*), *J. Agric. Food Chem*., 48, 1307, 2000.
102. Cros, S. et al., Desalination of mussel cooking juices by electrodialysis: Effect on the aroma profile, *J. Food Eng*., 69, 425, 2005.
103. Morita, K., Kubota, K., and Aishima, T., Sensory characteristics and volatile components in aromas of boiled prawns prepared according to experimental designs, *Food Res. Int*., 34, 473, 2001.
104. Morita, K., Kubota, K., and Aishima, T., Comparison of aroma characteristics of 16 fish species by sensory evaluation and gas chromatographic analysis, *J. Sci. Food Agric*., 83, 289, 2003.
105. Whitfield, F.B. et al., Distribution of bromophenols in species of marine polychaetes and bryozoans from eastern Australia and the role of such animals in the flavor of edible ocean fish and prawns (shrimp), *J. Agric. Food Chem*., 47, 4756, 1999.
106. Chung, H.Y., Ma, W.C.J., and Kim, T.S., Seasonal distribution of bromophenols in selected Hong Kong seafood, *J. Agric. Food Chem*., 51, 6752, 2003.
107. Boyle, J.L., Lindsay, R.C., and Stuiber, D.A., Bromophenol distribution in salmon and selected seafoods of fresh-water and saltwater origin, *J. Food Sci*., 57, 918, 1992.
108. Ma, W.C.J. et al., Enhancement of bromophenol levels in aquacultured silver seabream (*Sparus sarba*), *J. Agric. Food Chem*., 53, 2133, 2005.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

109. da Silva, V.M. et al., Determination of simple bromophenols in marine fishes by reverse-phase high performance liquid chromatography (RP-HPLC), *Talanta*, 68, 323, 2005.
110. Chaintreau, A. Simultaneous distillation-extraction: From birth to maturity—Review, *Flavour Fragrance J.*, 16, 136, 2001.
111. Acree, T.E., Bioassays for flavour, in *Flavor Science: Sensible Principles and Techniques*, Acree, T.E. and Teranishi, R., Eds., American Chemical Society, Washington, DC, 1993, p. 1.
112. Kubota, K. et al., Identification and formation of characteristic volatile compounds from cooked shrimp, in *Thermal Generation of Aromas*, Parliament, T.H., McGorrin, R.J., and Ho, C.-T., Eds., American Chemical Society, Washington, DC, 1989, p. 376.
113. Elmore, J.S., Mottram, D.S., and Dodson, A.T., Meat aroma analysis: Problems and solutions, in *Handbook of Flavor Characterization: Sensory Analysis, Chemistry, and Physiology*, Deibler, K.D. and Delwiche, J., Eds., Marcel Dekker, Inc., New York, 2004, p. 295.
114. Lee, G.H., Suriyaphan, O., and Cadwallader, K.R., Aroma components of cooked tail meat of American lobster (*Homarus americanus*), *J. Agric. Food Chem.*, 49, 4324, 2001.
115. Cha, Y.J. and Cadwallader, K.R., Aroma-active compounds in skipjack tuna sauce, *J. Agric. Food Chem.*, 46, 1123, 1998.
116. Triqui, R. and Guth H., Determination of potent odorants in ripened anchovy (*Engraulis encrasicholus* L.) by aroma extract dilution analysis and by gas chromatography-olfactometry of headspace samples, in *Flavor and Lipid Chemistry of Seafoods*, Shahidi, F. and Cadwallader, K.R., Eds., American Chemical Society, Washington, DC, 1997, p. 31.
117. Triqui, R. and Zouine, K., Sensory and instrumental assessments of the ripening process of anchovy (*Engraulis encrasicholus*), *Food Sci. Technol.*, 32, 203, 1999.
118. Schlüter, S. et al., Changes in the odorants of boiled carp fillet (*Cyprinus carpio* L.) as affected by increasing methionine levels in feed, *J. Agric. Food Chem.*, 47, 5146, 1999.
119. Engel, W., Bahr, W., and Schieberle, P., Solvent assisted flavour evaporation—A new and versatile technique for the careful and direct isolation of aroma compounds from complex food matrices, *Eur. Food Res. Technol.*, 209, 237, 1999.
120. Girard, B. and Nakai, S., Nonparametric discriminant analysis of static headspace volatiles for grading fresh Pacific salmon, *J. Food Qual.*, 17, 409, 1994.
121. Medina, I., Satué-Gracia, M.T., and Frankel, E.N., Static headspace gas chromatographic analyses to determine oxidation of fish muscle lipids during thermal processing, *JAOCS*, 76, 231, 1999.
122. Hollingworth, T.A., Jr., Throm, H.R., and Wekell, M.M., Determination of ethanol in canned salmon, in *Seafood Quality Determination*, Kramer, D.E. and Liston, J., Eds., Elsevier, Amsterdam, the Netherlands, 1987, p. 153.
123. Chantarachotti, J. et al., Alaska pink salmon (*Onchorynchu gorbuscha*) spoilage and ethanol incidence in the canned product, *J. Agric. Food Chem.*, 55, 2517, 2007.
124. McLachlan, D.G., Wheeler, P.D., and Sims, G.G., Automated gas chromatographic method for the determination of ethanol in canned salmon, *J. Agric. Food Chem.*, 47, 217, 1999.
125. Lindsay, R.C., Josephson, D.B., and Olafsdottir, G., Chemical and biochemical indices for assessing the quality of fish packaged in controlled atmospheres, in *Seafood Quality Determination*, Kramer, D.E. and Liston, J., Eds., Elsevier, Amsterdam, the Netherlands, 1987, p. 221.
126. Yasuhara, A. and Shibamoto, T., Quantitative analysis of volatile aldehydes formed from various kinds of fish flesh during heat treatment. *J. Agric. Food Chem.*, 43, 94, 1995.
127. Kolb, B. and Ettre, L., *Static Headspace-Gas Chromatography: Theory and Practice*, 2nd edn., Wiley, Chichester, U.K., 2006, p. 376.
128. Matiella, J.E. and Hsieh, T.C.Y., Analysis of crabmeat volatile compounds, *J. Food Sci.*, 55, 962, 1990.
129. Zhang, C.H. et al., Studies on the odor of fishes. 3. Volatile compounds and their generation in smelt, *Nippon Suisan Gakkaishi*, 58, 773, 1992.
130. Kawai, T. et al., Flavor components of dried squid, *J. Agric. Food Chem.*, 39, 770, 1991.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

131. Josephson, D.B., Lindsay, R.C., and Stuiber, D.A., Identification of compounds characterizing the aroma of fresh whitefish (*Coregonus clupeaformis*), *J. Agric. Food Chem*., 31, 326, 1983.
132. Josephson, D.B., Lindsay, R.C., and Stuiber, D.A., Variations in the occurrences of enzymically derived volatile aroma compounds in saltwater and fresh-water fish, *J. Agric. Food Chem*., 32, 1344, 1984.
133. Josephson, D.B., Lindsay, R.C., and Stuiber, D.A., Influence of maturity on the volatile aroma compounds from fresh Pacific and Great Lakes Salmon, *J. Food Sci*., 56, 1576, 1991.
134. Josephson, D.B., Lindsay, R.C., and Stuiber, D.A., Volatile compounds characterizing the aroma of fresh Atlantic and Pacific oysters, *J. Food Sci*., 50, 5, 1985.
135. Ishizaki, S. et al., Evaluation of odour-active compounds in roasted shrimp (Sergia lucens Hansen) by aroma extract dilution analysis, *Flavour Fragrance J*., 20, 562, 2005.
136. Hallier, A., Prost, C., and Serot, T., Influence of rearing conditions on the volatile compounds of cooked fillets of *Silurus glanis* (*European catfish*), *J. Agric. Food Chem*., 53, 7204, 2005.
137. Hallier, A., Serot, T., and Prost, C., Odour of cooked silurus (*Silurus glanis*) flesh: evaluation by sensory analysis and comparison of collection methods to assess the odour representativeness of extracts obtained by dynamic headspace, *J. Sci. Food Agric*., 84, 2113, 2004.
138. Hallier, A. et al., New gas chromatography-olfactometric investigative method, and its application to cooked *Silurus glanis* (European catfish) odor characterization, *J. Chromatogr. A*, 1056, 201, 2004.
139. Aro, T. et al., Volatile compounds of Baltic herring analysed by dynamic headspace sampling-gas chromatography-mass spectrometry, *Eur. Food Res. Technol*., 216, 483–488, 2003.
140. Piveteau, F. et al., Aroma of fresh oysters Crassostrea gigas: Composition and aroma notes, *J. Agric. Food Chem*., 48, 4851–4857, 2000.
141. Hsieh, T.C.Y. et al., Volatile flavor components in thermally processed Louisiana red swamp crayfish and blue crab, in *Thermal Generation of Aromas*, Parliament, T.H., McGorrin, R.J., and Ho, C.-T., Eds., American Chemical Society, Washington, DC, 1989, p. 386.
142. Vejaphan, W., Hsieh, T.C.Y., and Williams, S.S., Volatile flavor components from boiled crayfish (*Procambarus Clarkii*) tail meat, *J. Food Sci*., 53, 1666, 1988.
143. Jorgensen, L.V., Huss, H.H., and Dalgaard, P., Significance of volatile compounds produced by spoilage bacteria in vacuum-packed cold-smoked salmon (*Salmo salar*) analyzed by GC-MS and multivariate regression, *J. Agric. Food Chem*., 49, 2376, 2001.
144. Refsgaard, H.H.F., Haahr, A.M., and Jensen, B., Isolation and quantification of volatiles in fish by dynamic headspace sampling and mass spectrometry, *J. Agric. Food Chem*., 47, 1114, 1999.
145. Methven, L. et al., Influence of sulfur amino acids on the volatile and non-volatile components of cooked salmon (*Salmo salar*), *J. Agric. Food Chem*., 55, 1427, 2007.
146. Jonsdottir, R. et al., Flavor characterization of ripened cod roe by gas chromatography, sensory analysis, and electronic nose, *J. Agric. Food Chem*., 52, 6250, 2004.
147. Andersen, E., Andersen, M.L., and Baron, C.P., Characterization of oxidative changes in salted herring (*Clupea harengus*) during ripening, *J. Agric. Food Chem*., 55, 9545, 2007.
148. Aidos, I. et al., Volatile oxidation products formed in crude herring oil under accelerated oxidative conditions, *Eur. J. Lipid Sci. Technol*., 104, 808, 2002.
149. Zhang, Z.Y. and Pawliszyn, J., Headspace solid-phase microextraction, *Anal. Chem*., 41, 809, 1993.
150. Kataoka, H., Recent advances in solid-phase microextraction and related techniques for pharmaceutical and biomedical analysis, *Curr. Pharm. Anal*., 1, 65, 2005.
151. Shirey, R.E., Optimization of extraction conditions for low-molecular-weight analytes using solid-phase microextraction, *J. Chromatogr. Sci*., 38, 109, 2000.
152. Song, X.A. et al., Volatile compounds in the hepatic and muscular tissues of common carp, Japanese flounder, Spanish mackerel and skipjack, in *More Efficient Utilization of Fish and Fish Products*, Sakaguchi, M., Ed., Elsevier, Amsterdam, the Netherlands, 2004, p. 209.
153. Linder, M. and Ackman, R.G., Volatile compounds recovered by solid-phase microextraction from fresh adductor muscle and total lipids of sea scallop (*Placopecten magellanicus*) from Georges Bank (Nova Scotia), *J. Food Sci*., 67, 2032, 2002.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

154. Mansur, M.A. et al., Volatile flavor compounds of some sea fish and prawn species, *Fisheries Sci*., 69, 864, 2003.
155. Wang, Q., O'Reilly, J., and Pawliszyn, J., Determination of low-molecular mass aldehydes by automated headspace solid-phase microextraction with in-fibre derivatisation. *J. Chromatogr. A*, 1071, 147, 2005.
156. Bianchi, F. et al., Fish and food safety: Determination of formaldehyde in 12 fish species by SPME extraction and GC-MS analysis, *Food Chem*., 100, 1049, 2007.
157. Chan, S.T. et al., Evaluation of chemical indicators for monitoring freshness of food and determination of volatile amines in fish by headspace solid-phase microextraction and gas chromatography-mass spectrometry, *Eur. Food Res. Technol*., 224, 67, 2006.
158. Li, X.J. et al., Novel fiber coated with amide bridged-calix[4]arene used for solid-phase microextraction of aliphatic amines, *J. Chromatogr. A*, 1041, 1, 2004.
159. Howgate, P., Tainting of farmed fish by geosmin and 2-methyl-iso-bomeol: A review of sensory aspects and of uptake/depuration, *Aquaculture*, 234, 155, 2004.
160. Heil, T.P. and Lindsay, R.C., A method for quantitative-analysis of flavor-tainting alkylphenols and aromatic thiols in fish, *J. Environ. Sci. Health Part B: Pestic. Food Contam. Agric. Wastes*, 23, 475, 1988.
161. Robin, J. et al., Off flavor characterization and origin in French trout farming, *Aquaculture*, 260, 128, 2006.
162. Schrader, K.K. et al., Geosmin and 2-methylisoborneol cause off-flavors in cultured largemouth bass and white sturgeon reared in recirculating-water systems, *North Am. J. Aquaculture*, 67, 177, 2005.
163. Grimm, C.C. et al., Using microwave distillation-solid-phase microextraction-gas chromatography-mass spectrometry for analyzing fish tissue, *J. Chromatogr. Sci*., 38, 289, 2000.
164. Conte, E.D. et al., Determination of geosmin and methylisoborneol in catfish tissue (*Ictalurus punctatus*) by microwave-assisted distillation-solid phase adsorbent trapping, *J. Agric. Food Chem*., 44, 829, 1996.
165. Johnsen, P.B. and Lloyd, S.W., Influence of fat-content on uptake and depuration of the off-flavor 2-methylisoborneol by channel catfish (*Ictalurus punctatus*), *Can. J. Fisheries Aquatic Sci*., 49, 2406, 1992.
166. Lloyd, S.W. and Grimm, C.C., Analysis of 2-methylisoborneol and geosmin in catfish by microwave distillation-solid phase microextraction, *J. Agric. Food Chem*., 47, 164, 1999.
167. Kondjoyan, N. and Berdagué, J.-L., *A Compilation of Relative Retention Indices for the Analysis of Aromatic Compounds*, INRA de Theix, Saint Genes Champanelle, France, 1996.
168. Mukhopadhyay, R., Old reliable benchtop GC/MS, *Anal. Chem*., 76, 213A, 2004.
169. Adahchour, M., Beens, J., and Brinkman, U.A., Recent developments in the application of comprehensive two-dimensional gas chromatography, *J. Chromatogr. A*, 1186, 67, 2008.
170. Čajka, T. and Hajslová, J., Gas chromatography–time-of-flight mass spectrometry in food analysis, *LC-GC Eur*., 2007, 25, 2007.
171. Milo, C. and Blank, I., Quantification of impact odorants in food by isotope dilution assay: Strengths and limitations, in *Flavor Analysis: Developments in Isolation and Characterization*, Mussinan C.J. and Morello M.J., Eds., American Chemical Society, Washington, DC, 1998, p. 69.
172. d'Acampora Zellner, B. et al., Gas chromatography-olfactometry in food flavour analysis, *J. Chromatogr. A*, 1186, 123, 2008.
173. Senger-Emonnot, P. et al., Odour active aroma compounds of sea fig (*Microcosmus sulcatus*), *Food Chem*., 97, 465, 2006.
174. Du, W.X. et al., Microbiological, sensory, and electronic nose evaluation of yellowfin tuna under various storage conditions, *J. Food Prot*., 64, 2027, 2001.
175. Pavón, J.L.P. et al., Strategies for qualitative and quantitative analyses with mass-spectrometry-based electronic noses, *Trends Anal. Chem*., 25, 257, 2006.
176. Ratel, J. et al., Mass spectrometry based sensor strategies for the authentication of oysters according to geographical origin, *J. Agric. Food Chem*., 56, 321, 2008.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

177. Taylor, A.J. and Linforth, R.S.T., Atmospheric pressure ionisation mass spectrometry for in vivo analysis of volatile flavour release, *Food Chem*., 71, 327, 2000.
178. Blake, R.S. et al., Demonstration of proton-transfer reaction time-of-flight mass spectrometry for real-time analysis of trace volatile organic compounds, *Anal. Chem*., 76, 3841, 2004.
179. Rochat, S., de Saint Laumer, J.-Y., and Chaintreau, A., Analysis of sulfur compounds from the in-oven roast beef aroma by comprehensive two-dimensional gas chromatography, *J. Chromatogr. A*, 1147, 85, 2007.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 15

Quality Index Methods

Grethe Hyldig, Emilía Martinsdóttir, Kolbrún Sveinsdóttir, Rian Schelvis, and Allan Bremner

Contents

15.1 Introduction 267
15.2 QIM 268
15.2.1 How to Use QIM 272
15.2.1.1 QIM Assessors 273
15.2.1.2 QIM Sessions 273
15.2.1.3 QIM Results 275
15.2.2 Development of New QIM Schemes 276
15.2.2.1 The Raw Material 276
15.2.2.2 Setting Up the QIM Scheme and Testing the Scheme 277
15.2.2.3 Validation of the QIM Scheme 279
15.2.3 QIM in Relation to the EU-Scheme 280
15.3 Conclusion 281
References 281

15.1 Introduction

The Quality Index Method (QIM) is a sensory analysis using a category scale, where the scheme measures the degree and rate of change in important criteria and in the sum total of these changes, which can be interpreted into equivalent days of storage and remaining shelf life. The development of the first QIM schemes were based on the work by Bremner [1] and are for whole fish stored in ice. There are now also QIM schemes developed for cod and plaice fillet [2,3] and for

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

frozen cod [4–6]. The QIM scheme for frozen cod measures the storage history [5]. The QIM schemes have been developed from the viewpoint of the industry and from technical research, but there have also been studies on developing a version for the consumer QIM (C-QIM; C for consumer) [7,8]. C-QIM is not an acceptance test, but a tool for decision making for the consumer buying fish in a market or at the fishmonger [9].

The principle in the QIM scheme is based on the proposition that assessors cannot judge degrees of perfection but can very readily detect deviations or changes from it. A simple illustration of this would be a crack in an otherwise perfect wall. Thus defects in the product were allotted demerit points, which were summed to a total to provide an overall evaluation. The higher the number of demerit points, the more defects the product had. This approach was derived from the understanding that during storage of fish, changes occur that are readily detectable and often measurable. This is also in keeping with the fact that the vast majority of chemical, biochemical, and microbiological tests on fish products start from either zero or a low value and increase with both temperature and period of storage.

The parameter for the QIM scheme is based on significant, well-defined characteristic changes of outer appearance attributes (eyes, skin, gills, and smell) for raw fish. In addition, the scoring allotted to each criterion is such that no single criterion could dominate and that the score values are easy to judge. The QIM scheme can be seen as a list of attributes each of which is scored on a restricted scale (0–3) and the scores are then added to provide a total—a quality index (QI).

The QIM schemes are developed in such a way that there is a straight-line relationship with period of storage of the fish [1,10–16]. Further trials and theoretical investigations underpinned the validity of the scheme and demonstrated that it was capable of integrating the effects of time and temperature during storage [12,13,17]. The slope of the line is the rate of demerit point accumulation per day of storage and a simple calculation can indicate the equivalent of the number of days at 0°C that the product has been stored. If the decision had been made at which value the product should no longer be sold, or where it crosses some arbitrary set boundary between product grades, then the remaining shelf life can be calculated for the appropriate end use.

Some of the problems among earlier schemes, such as the EU-scheme [18] are that they do not take into account the difference between species. To do that it is necessary to develop one scheme for each species. QIM does take the inherent differences between fish species into account and therefore it is necessary to develop QIM schemes for each fish species. This can be illustrated in the parameters for the eyes in the QIM scheme for cod (*Gadus morhua*) and salmon (*Salmo salar*) (Tables 15.1 and 15.2). There is a three-quality parameter concerning the eyes in the scheme for cod (corona, form of the eyes, and the pupil) and only two in the scheme for salmon (pupil and form of the eyes). Another example is that texture is not a parameter in the QIM scheme for plaice (*Pleuronectes platessa*), because here texture is not easy to measure and it does not change much during storage.

In the following sections the QIMs for whole fish storage in ice are described in detail.

15.2 QIM

Today, several QIM schemes have been developed and the QIM-Eurofish Foundation (www.qim-eurofish.com) have published a QIM reference manual for the fish industry in 11 European languages (Danish, Dutch, English, French, German, Greek, Icelandic, Italian, Norwegian, Portuguese, and Spanish) covering 13 QIM schemes for commercially important species [19]. QIM schemes for the following fish species are published: brill (*Rhombus laevis*), cod (*G. morhua*), deep

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 15.1 QIM Scheme for Whole Farmed Salmon (*S. salar*) Containing Description for Each Parameter and the Given Scores in Succession from 0 to 3

Quality Parameters		*Description*	*Score*
Skin	Color/appearance	Pearl-shiny all over the skin	0
		The skin is less pearl-shiny	1
		The fish is yellowish, mainly near the abdomen	2
	Mucus	Clear, not clotted	0
		Milky, clotted	1
		Yellow and clotted	2
	Odor	Fresh sea weedy, neutral	0
		Cucumber, metal, hay	1
		Sour, dish cloth	2
		Rotten	3
	Texture	In rigor	0
		Finger mark disappears rapidly	1
		Finger leaves mark over 3 s	2
Eyes	Pupils	Clear and black, metal shiny	0
		Dark gray	1
		Matt, gray	2
	Form	Convex	0
		Flat	1
		Sunken	2
Gills	Color/appearance	Red/dark brown	0
		Light red, pink/hazel	1
		Gray-brown, brown, gray, green	2
	Mucus	Transparent	0
		Milky, clotted	1
		Brown, clotted	2
	Odor	Fresh, seaweed	0
		Metal, cucumber	1
		Sour, moldy	2
		Rotten	3

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 15.1 (continued) QIM Scheme for Whole Farmed Salmon (*S. salar*) Containing Description for Each Parameter and the Given Scores in Succession from 0 to 3

Quality Parameters		*Description*	*Score*
Abdomen	Blood in abdomen	Blood red/not present	0
		Blood more brown, yellowish	1
	Odor	Neutral	0
		Cucumber, melon	1
		Sour, reminds of fermentation	2
		Rotten/rotten kale	3
QI (0–24)			

Table 15.2 QIM Scheme for Whole Farmed Cod (*G. morhua*) Containing Description for Each Parameter and the Given Scores in Succession from 0 to 3

Quality Parameter		*Description*	*Score*
Appearance	Skin	Bright, iridescent pigmentation	0
		Rather dull, becoming discolored	1
		Dull	2
	Stiffness	In rigor	0
		Firm, elastic	1
		Soft	2
		Very soft	3
Eyes	Cornea	Clear	0
		Opalescent	1
		Milky	2
	Form	Convex	0
		Flat, slightly sunken	1
		Sunken, concave	2
	Color of pupil	Black	0
		Opaque	1
		Gray	2

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 15.2 (continued) QIM Scheme for Whole Farmed Cod (*G. morhua*) Containing Description for Each Parameter and the Given Scores in Succession from 0 to 3

Quality Parameter		*Description*	*Score*
Gills	Color	Bright	0
		Less colored, becoming discolored	1
		Discolored, brown spots	2
		Brown, discolored	3
	Smell	Fresh, sea weedy, metallic	0
		Neutral, grassy, musty	1
		Yeast, bread, beer, sour milk	2
		Acetic acid, sulfuric, very sour	3
	Mucus	Clear	0
		Milky	1
		Milky, dark, opaque	2
Blood	Color	Red	0
		Dark red	1
		Brown	2
Fillets	Color	Translucent, bluish	0
		Waxy, milky	1
		Opaque, yellow, brown spots	2
QI (0–23)			

water shrimp (*Pandalus borealis*), farmed salmon (*Salmo salar*), whole fjord shrimp (*P. borealis*), haddock (*Melanogrammus aeglefinus*), herring (*Clupea harengus*), peeled shrimp (*P. borealis*), plaice (*P. platessa*), pollock (*Pollachius virens*), redfish (*Sebastes mentella/marinus*), sole (*Solea vulgaris*), and turbot (*Scophthalmus maximus*).

Moreover Andrade et al. [20] have published schemes for Atlantic mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*), and European sardine (*Sardina pilchardus*), Barbosa and Vaz-Pirez [21] a QIM scheme for common octopus (*Octopus vulgaris*), Huidobro et al. [11] for raw gilthead Sea bream (*Sparus aurata*), Baixas-Nogueras et al. [22] for Mediterranean Hake (*Merluccius merluccius*), Pons-Sánchez-Cascado et al. [23] for Mediterranean anchovies (*Engraulis encrasicholus*), and Herrero et al. [6] for frozen Hake (*M. capensis and M. paradoxus*). Furthermore QIM schemes have been developed for cod fillets (*G. morhua*) [3], flounder (*Paralichthys patagonicus*) [24], air and MA-packed maatjes herring (*C. harengus*) [25], cuttlefish (*Sepia officinalis*), and broadtail shortfin

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

squid (*Illex coindetii*) [26], farmed Atlantic halibut (*Hippoglossus hippoglossus L.*) [27], and tub gunard (*Chelidonichthys lucernus*) [28].

Collaborative work has resulted in development of the Australian Quality Index Manual [29] that in its first version contains schemes for six species: Atlantic salmon (*S. salar*) in the head-on, gilled, and gutted form, whole Goldband snapper (*Pristipomoides multidens*), whole Sea mullet (*Mugil cephalus*), whole Snapper (*Pagrus auratus*), whole Tiger flathead (*Neoplatycephalus richardsonii*), and cooked whole Black tiger prawns (*Penaeus monodon*). A second version with schemes for another eight species will be released at the end of 2008. Tables 15.1 and 15.2 show the schemes for salmon and cod.

15.2.1 How to Use QIM

QIM is an objective method and, is easy to work with, since it includes instructions and easily understood illustrational material. Training QIM assessors for the industry implies both training for being a sensory assessor, including the standard sensory procedures, as well as training for implementation of QIM in practice. The sampling system, methods, and procedures for sensory evaluation must be very well defined to serve its purpose in quality management. QIM is well suited to train assessors and monitor performance of the panel. The QIM sessions must take place without any disturbance among the assessors. Assessors should know the nature and limits of the sense organs and learn how to recognize and evaluate appearance, taste, odor, and texture of fish after different periods of storage.

Sensory evaluation of whole fish is generally carried out by trained assessors in the reception or processing halls of fish factories or at auction sites. In quality control procedures, special facilities or rooms are preferred for sensory evaluation, but it is not always possible. In industry and auctions the testing area should be located giving consideration to what is practical.

The demands for the testing areas are

1. The noise level shall be kept to a minimum; during a sensory session the assessors must be able to work without any interruption.
2. Lighting is very important. It is preferable that the light is either real daylight according to ISO standard [30] but as a minimum be an intensity of 600–1500 lx/m^2.
3. It must be free of any foreign odors. As a minimum there must not be any waste or other matter, or operation with a strong smell nearby.
4. There must be no eating, drinking, or smoking allowed in the testing area.
5. Testing area must be easy to clean and disinfect. Regular cleaning and disinfecting shall take place. It must be ensured that the cleaning agents used do not leave odors in the testing area.
6. The temperature should be kept low and constant.

The aim of nonbiased sampling is to obtain a representative random sample from a lot. It is vital that the sample is selected randomly to ensure that it is representative. The number of fish to be sampled is determined by the accepted uncertainty, the characteristic of the lot, and economy [31,32].

From a defined homogeneous lot, preferably three to five fish (10 for small fish species) should be assessed according to QIM schemes. An homogeneous lot of fish should be assessed, i.e., from the same catching day. Number the boxes in a standard way, for example always from

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

left to right and from top to bottom and generate 3–10 random numbers. Take one fish out of each of the 3–10 numbered boxes as decided. Make sure the fishes are taken from different places in the boxes (not always from the top layer). Evaluate all 3–10 fish using the QIM schemes as provided.

15.2.1.1 QIM Assessors

QIM assessors must be selected on their ability to evaluate appearance, color, odor, and texture. Assessors must also be healthy and possess normally sensitive taste and odor senses [33,34]. Personal characteristics are also very important such as conscientiousness and accuracy and they must be able to work in a group without disturbing the other assessors with noise, talk, and making faces. Depending on the regular duties of the individual, he or she must be readily available. For a company it is necessary to have a panel leader and a group of tested and trained assessors. The assessors for the QIM evaluation are then picked out from the group depending on availability, but it must be emphasized that all assessors in the sensory group are used frequently.

The training of the sensory panel should begin by describing the procedures of the sensory evaluation, what is expected of the assessors, etc. The nature and limits of the sense organs are described, such as the importance of breathing deeply and resting between samples during odor evaluation. The schemes intended for use must be carefully explained. The general descriptions of the parameters are shown in Table 15.3. It should be emphasized to the assessors that they must not let their hedonic personal judgment interfere with the evaluation.

For training, three to four samples of fish of different known storage periods in ice and treatment are used. The storage time of the fish is introduced to the assessors before they evaluate the fish and they are asked if they can agree on the scores that should be given for each sample. The samples are number coded. All assessors should become very familiar with fish of all freshness stages, i.e., not only raw material that is on the borderline of production. Training results should be evaluated. Average and standard deviation of each sample is calculated and a comparison is made between the assessors, i.e., by performing statistical analysis (analysis of variance, for example). The ability of the assessors can be examined during repeated evaluation of the same samples. Repetition of the training will show the capabilities of the assessors. Regular training of the sensory panel should be done and performance of the assessors monitored. It is also important to keep the assessors motivated. Finally the assessors must be able to perform QIM in a fast and accurate way and be in agreement with other QIM panels in proficiency tests.

15.2.1.2 QIM Sessions

The panel leader prepares the evaluation by giving the fish samples three-digit codes, and places the fish in random order on the table. They are kept cool either by placing them on a cooling plate or on ice. To avoid bias samples should always be coded with two- to three-digit numbers that provide no information about the samples. The samples must be kept cool under evaluation and the assessors should not see the samples being placed. The boxes where the samples have been taken from must also be removed from the testing area, because this might enhance expectation error. Order of presentation should be random and the order should be balanced. The assessors must be told in which order they should evaluate the samples.

Hunger or satiation can influence the performance of the assessors. The assessors must not eat or smoke for an hour before the sensory evaluation. The assessors must be quiet and concentrating

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 15.3 General Description of Parameters

Appearance	
It is important that the fish do not lie for such a long time that the skin dries out.	
Skin	The whole fish is inspected for the appearance of the skin and fins.
Mucus	The appearance of mucus on the skin is assessed. Mucus can be difficult to find on fish such as salmon, but it is often located around the dorsal fin.
Odor	The odor of the skin is assessed by smelling the spine. If the fish has been lying more than 15 min on the table, it should be turned over and smelled on the other side.
Texture	
Texture/firmness: The texture is assessed by pressing a finger (firmly, but not too hard) on the spine muscle and observing if/how fast the flesh recovers. Only fish in rigor is given a score of 0. Prerigor fish is soft/very soft and therefore given a high score, but if it is known that it is a prerigor fish, the texture should be 0.	
Belly	The consistency of the belly is assessed by pinching it between fingers or by stroking it with the fingertips.
Eyes	
Avoid touching the eyes with your fingers. If one eye is damaged, assess the other one. Eyes where the cornea is swollen are often difficult to assess, but the membrane may be stung or cut for easier assessment of the eye.	
Cornea	Color and clearness of the cornea is assessed.
Form	The form of the eyes is assessed by looking at the eye directly or from the side.
Gills	
The gills are assessed by lifting the opercula. If the gills have been cut on one side of the fish, assess the gills that have not been cut. Avoid touching the gills since the appearance and mucus of gills can easily be destroyed.	
Gill color	The color of the gills is assessed.
Gill odor	Odor of the gills is assessed by, lifting the opercula and smelling by the gill bow.
Mucus in gills	Color and appearance of the mucus is assessed.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 15.3 (continued) General Description of Parameters

Viscera
Fish kept in ice with the viscera (ungutted) must be opened. The appearance of the viscera is assessed.
Color of Blood in Abdomen
Usually, remains of blood in abdomen are visible in gutted fish. Blood may also be assessed in the cut wound (near the gills), if no remaining blood is left in the abdomen.
Odor in Abdomen
Odor in the abdomen is assessed by smelling inside the abdomen.
Fillets/Cut Surface
Color of fillets is assessed by the cut surface at the flaps or by assessing the fillets. Some fish such as redfish must be filleted from one side to be able to see the fillets and viscera.

during the evaluation. Trained assessors can evaluate 40 fish with QIM in 20 min, and the method is nondestructive.

During continuous assessment of odor, assessors become insensitive to odors after some time. People become desensitized to odors as the receptors in the olfactory senses become saturated. Therefore, it is necessary to rest and breathe fresh air between samples when evaluating odor. Also, by taking a deep breath, the airflow through the olfactory senses increases and the odor becomes easier to detect.

When applying the QIM schemes, the outer appearance of the fish, eyes, gills, and texture are evaluated. The odor of gills is evaluated, and for some species the odor and mucus of the skin is also evaluated. The color of blood, and fillets (or the cut surface at the flaps) is evaluated in gutted fish. All attributes are to be assessed in the same order for each fish. For some fish species that are not gutted, such as redfish, dissolution of viscera is evaluated as well.

The assessor must evaluate *all* the parameters involved in the scheme (he or she cannot determine which parameters are most important). The assessors write down the scores given. For (quality) control purposes it is important to write down the information about the batch, date of assessment, and name of the assessors prior to assessing the fish. To make the scheme uniform and easy to use and to ensure all criteria were scored it was programmed into a handheld computer [35–37] and a prototype dedicated handheld device was developed [17]. An Icelandic company has developed software which can be connected to a handheld computer. The software includes both QIM schemes and photographs of fish at different spoilage stage, but this instrument is not commercially available [38].

15.2.1.3 QIM Results

The scores for all the characteristics are summarized to give an overall sensory score, the so-called QI. If a score for one of the parameters is missing, it is not possible to calculate the total sum and thereby the QI for the assessed fish. If this situation is an incident (for example damaged eyes

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

makes it impossible to assess this attribute) the best way to deal with it is to leave that particular fish out and take another sample. If it occurs on a regular basis (for example, due to washing procedures at a company the mucus is always removed) the scheme should be adapted and a new calibration curve constructed in which the particular attribute (e.g., mucus) is removed.

Having the QI on an electronic basis means the data can be rapidly communicated from a boat, the quayside, or an auction, and that it can be used in management systems to plan supply and production and to allocate product to different grades or to end uses according to production or market requirements. The full assessment data can be stored in databases. This ability to transmit a meaningful QI along with identity and traceability information over the Internet represents a major advantage and a progressive step in electronic marketing of fish products. It further enhances opportunities for quality chain management to ensure product of known properties is handled correctly along the supply chain.

As the QI increases linearly with storage time in ice, the information may be used in production management [19]. From the QI results, an estimate can be calculated for the remaining shelf life (equals total shelf life minus predicted storage time). In the following the calibration curves for cod, salmon, and plaice are shown:

$$\text{Cod: QI} = 1.20 \times \text{days in ice} - 0.04 \quad (R^2 = 0.966)$$

$$\text{Salmon: QI} = 0.692 \times \text{days in ice} + 1.57 \quad (R^2 = 0.953)$$

$$\text{Plaice: QI} = 1.28 \times \text{days in ice} \quad (R^2 = 0.89)$$

It is emphasized that remaining shelf life should be used with some precaution due to the uncertainty in the estimation. Various factors can affect the remaining shelf life. It depends on the handling of the fish. Rapid cooling after the catch and an uninterrupted cold storage, different fishing gear, bleeding, and gutting methods are important, and the season and catching ground can also have an effect. In the literature several storage studies are reported and the estimated shelf life of different species is recorded [12,13,39–43]. These are summarized in Table 15.4.

15.2.2 Development of New QIM Schemes

To develop a new QIM scheme there are several considerations to take into account. It is necessary to have some specific knowledge about the fish species, to have on hand two tested and trained sensory panels, a facility to conduct storage experiments under standardized conditions, and to be able to make a statistical validation of the developed QIM scheme. In the following paragraphs this standardized development is described in detail.

15.2.2.1 The Raw Material

The selection of fish species is based on practical considerations and economic value. The fishing gear used to catch them and the fishing grounds where they are caught correspond with this selection and are fixed for QIM schemes. The handling of the fish should be according to Good Manufacturing Practice (GMP) [32]. GMP can mean various standards or technical specifications, such as that the fish is gutted at sea (if gutting is the normal procedure) and washed. The fish is directly cooled down to 0°C in melting ice or equivalent cooling media. The fish is stored

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 15.4 The Estimated Shelf Life for Some Fish Species

Species	*Estimated Shelf Life in Ice*
Brill (*R. laevis*)	14 days
Cod (*G. morrhua*)	15 days
Deep water shrimp (*P. borealis*)	6 days
Farmed salmon (*S. salar*)	20 days
Fjord shrimp (*P. borealis*)	6 days
Haddock (*M. aeglefinus*)	15 days
Herring (*C. harengus*)	8 days
Peeled shrimp (*P. borealis*)	6 days[a]
Plaice (*P. platessa*)	13 days
Pollock (*P. virens*)	18 days
Redfish (*S. mentella/marinus*)	18 days
Sole (*S. vulgaris*)	15 days
Turbot (*S. maximus*)	15 days

[a] The storage life before peeling.

in fish boxes, with sufficient ice, which may be replenished, during the whole storage period. The storage trials begin with homogeneous batches of fish, preferably from one haul, with known history such as date of catch, storage condition, etc. For the complete development of a new QIM scheme at least three storage trials are needed and the experiment must begin at the time of catch and continue till after the end of shelf life. The QIM schemes developed with these batches are valid for these conditions.

15.2.2.2 Setting Up the QIM Scheme and Testing the Scheme

For the development of a draft QIM scheme, the first storage experiment is needed. In this stage the fish is described in detail during the complete ice storage until the end of an expected shelf life. This is done at fixed time intervals of 12–48 h, depending on the expected shelf life of the species. The shorter the expected shelf life is, the shorter the time intervals required. A group of maximum five experienced assessors, including a panel leader, is put together. This group is selected, besides the usual criteria for sensory assessors, for their good use of vocabulary and knowledge of the fish species. The panel leader is experienced in control of the discussion and enables everyone to express their meaning. Approximately five fishes are used at the time and they are discarded after each session. During the sessions the fishes are placed on chill plates or ice. Further sessions are continued until the fish is completely spoiled. All attributes are listed and described in detail. The attributes to be assessed varies per species: for example for flat fish species the appearance of both sides might be relevant which is, obviously, not the case for round fish species. The appearance for shrimp will

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

have a completely different description than for cod. All descriptions are written down, preferably in terms the whole group agrees on. A description is written on how the assessment is done, for example the assessment of the texture attribute for cod is done by pressing the finger (firmly but not too hard) on the spine muscle and observing how fast the flesh recovers.

After this first storage trial, the panel leader selects those attributes that change over the storage period, the descriptions are grouped together per attribute and major changes are scored with "demerit" points from 0 to 3. If, for example, the maximum of three demerit points are scored within the first 5 days, but it is generally known that then the shelf life is, in total, about 14 days, the description per demerit point needs to be changed in such a way that the scoring covers more of the complete shelf life. This results in the draft QIM scheme that will be used in the next storage trial.

The testing of the draft QIM scheme is done with a second batch of fish during a new storage trial. For this test a new panel of approximately 10 assessors (experts in QIM) is organized, the assessors who participated in the development of the scheme are included.

During the storage trial at fixed time intervals, again depending on the shelf life but less frequently than in the first storage trial, five fishes are assessed individually by using the draft QIM scheme. Each expert scores every attribute and comments are written down. After each session the scores, comments, and questions on how to assess the attributes are discussed among the assessors. The results are analyzed and the attributes are selected for being discriminative and for ease of assessment. Statistical analyses used to assist these decisions are Principal Component Analyses (PCA) or calculation of linear regression lines per attribute [12,13]. These decisions on attributes and scores are of major importance for meeting several of the above-mentioned considerations like the balance between the strength of the scheme, reliability of the results, and practical use of the scheme, and cannot be made without knowledge on the fish species, spoilage pattern, practical importance of the sensory attributes, and QIM principles in general.

At the same time the draft scheme is tested the end of shelf life needs to be determined. The shelf life is defined as the number of days that whole, fresh (gutted) fish can be stored in ice until it becomes unfit for human consumption. It needs to be emphasized that the estimated shelf life is based upon optimal catching and storage conditions [12,13,19].

Spoilage due to microbial activity is the main limitation of the shelf life. Another cause of spoilage may be rancidity, especially in fatty fish species. The flesh of newly caught fish is free of bacteria. However, considerable amounts of bacteria may be in the viscera, the gills, and on the skin, which can give contamination during processing. When the fish is stored whole in ice, the deterioration caused by bacteria is minimal for the first days of storage and then it will increase.

In general, when fish is stored in ice the flavor and odor compounds that characterize newly caught fish decrease and disappear in the first few days during storage, and the fish flesh becomes almost flavorless and odorless for a while. Then an increase in bad-smelling sulfur and nitrogenous volatiles will result in rejection of the fish for human consumption. This can be measured by descriptive sensory profiling or by using the Torry-scale. A tested and trained sensory panel evaluates cooked samples from the storage experiment. The sensory panel must be a second panel of different composition in order to overcome bias. The descriptive sensory profiling and the Torry-scale are described in the previous chapter. From the results of the descriptive sensory analysis the shelf life is defined.

For future use of the QIM scheme, i.e., training of QIM inspectors and illustration of the descriptions of the different attributes, pictures are of utmost importance. During the development of QIM, pictures need to be taken of all the changes of the different attributes. These pictures

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

are preferably taken by a professional photographer in order to be clear, and with the right use of flashlights. In practice the importance of the quality of the pictures and the difficulties in taking them are highly underestimated. This can result in low-quality pictures which are not suitable for printing in reference manuals.

The next step in the development of a QIM scheme is the so-called calibration curve. As mentioned in the introduction of this chapter, the QIM resulted in a scoring system that gave a linear relationship with storage period and the slope of the line is the rate of demerit point accumulation per day of storage. A simple calculation can indicate the equivalent of the number of days at 0°C that the product has been stored (i.e., predicted storage time). To calculate the calibration curve, a simple linear regression analysis is performed. The data for this calculation is obtained from a third more complex storage trial. Before this third trial the QIM panel is trained for the new developed QIM scheme. The QIM panel will assess according to good sensory practice. They will evaluate unknown coded samples in random order. This implies that, during the storage trial several new batches, which have been stored for different equivalent days in ice, are randomly allocated so that fish of different QIM are assessed in one session. From each batch five fishes are assessed within each trial and a maximum of five assessments are done per fish. If more than five assessors assess the fish a double batch is needed. The storage trial is finished when the fish is spoiled, meaning some days after the determined end of shelf life, in order to get a complete calibration curve for the QIM scheme.

The average results are used to calculate the linear regression. The equation is calculated as well as the variation around the curve. The intercept at the *y*-axis is of major importance and should be close to 0. This follows the QIM principle of "deviations from a perfect product." The correlation coefficient between the QI and the days in ice should be close to 1.0. With this result the calibration curves give reliable prediction of the storage time. The calculated Standard Error of Prediction (SEP) results in the reliability of the QIM assessments. Sveinsdóttir et al. [12,13] published results that with the assessment of three salmon per batch the reliability was 2 days, and with assessment of five salmon per batch the reliability was 1.5 day.

15.2.2.3 Validation of the QIM Scheme

To finalize the QIM scheme the foregoing steps need to be combined and will result in a QIM scheme that is more than only a table with attributes, descriptions, and scores. The scheme is developed under standardized conditions that need to be described in order to know the validity of the scheme under different circumstances.

If a scheme becomes too specific then it may not suit all the circumstances of catch and handling for that species. A fish caught by handline/longline will generally show fewer signs of deterioration than one caught by trawling, and its starting characteristics when stored in ice will be different. A trawled fish stored in refrigerated seawater will have a different appearance to those stored in ice [44]. In both these instances the QIM scores at the start of storage will be different, but later during the storage period any differences may be insignificant. Either a general scheme that does not differentiate on the basis of catch or storage medium should be used, or particular schemes should be developed that allow for this difference in properties. It depends on circumstances, anticipated storage life, and the use of the scheme. Huidobro et al. [45] reported that the QIM of washed sea bream developed similarly to that of unwashed sea bream for up till 10 days storage in ice. After that, less slime and lower trimethylamine (TMA) formation in the washed fish retarded the normal increase in score, in comparison to unwashed fish. This illustrates another

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

instance where the process may influence the score. But anticipated shelf life should also be taken into account since these were aquacultured sea bream destined for sale as fresh (i.e., unfrozen) fish. Clearly there would be a failure in the market and distribution system if such a prime product was not sold in much less than 10 days, and a scheme should not necessarily be required to cover all treatment options beyond this time.

To a large extent all changes in stored fish are governed by time and temperature with the proviso, as we have seen above, that species and catch and handling practices, and maybe seasonal factors, are similar. If the commercial fish handling system maintains fish at a steady temperature of 0°C then any lack of ability to integrate is not of concern. However, it is a matter of common and recorded observation that temperature in the fish chain is not always well controlled. It may be that some schemes provide an incorrect assessment depending on how long the fish has been at elevated temperatures. However, most other instruments and schemes have not been tested in this regard either. The Torrymeter for example cannot integrate time and temperature at the correct rate [17]. The original scheme, on which QIM is based, was shown to be capable of integrating the effects of time and temperature [46]. Experiments at the DTU AQUA (former Danish Institute for Fisheries Research) in 2003 were set up to check whether the developed QIM schemes could integrate the time/temperature effects. The results from experiments with cod and plaice showed that if the fish have been stored at elevated temperatures (between 0°C and 5°C) and then stored at 0°C, the development in QI would follow the calibration curve for the fish species.

Some tropical reef fish have inordinately long shelf-lives of more than 3 weeks when they are iced soon after catch and kept cold during storage [46]. This seems to be due to the absence of spoilage psychrotrophic bacteria, unless they are introduced, and to a stable level of IMP in the flesh. Consequently, the flesh remains acceptable in flavor for considerable periods of time when virtually all the external indicators that would be used in a QIM scheme, are at, or near, their maxima. However, it is still obvious that the fish have been stored for a considerable period and their remaining commercial life must be extremely limited. The use of a QIM approach for these species is still valid, but care must be taken in formulating a scheme in which the maximum QIM score is not reached while the fish is still quite marketable with some remaining shelf life.

To validate the new developed QIM scheme a storage experiment at another location, season, or catching ground can be conducted [12,13].

15.2.3 QIM in Relation to the EU-Scheme

Specific for seafood the EU regulation: "Council Regulation (EC) No. 2406/96 of 26 November 1996 [18], laying down common marketing standards for certain fishery products" has only one sensory method—the EU-scheme for fresh fish. This method is to be used at the first point of sale and implies freshness and other quality items (parasites, pressure marks, injuries, blemishes, and bad discoloration). There are different schemes for Whitefish, Bluefish, Selachii, Cephalopods, and Crustaceans. This method is to be used by experts or by the competent authority (inspection body). As already mentioned the EU-scheme does not take into account the differences between species as it only uses general parameters, and there are also problems with mixing subjective and objective sensory in the scheme. Several studies have shown that the QIM proved to be more reliable in assessing sensory changes of different fish species as compared to the EU grading scheme [47].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 15.5 The Relation between the EU Classification and the QI Score for Four Fish Species

EU Classification	*QI Score*			
	Plaice (P. platessa)	*Cod (G. morhua)*	*Sole (S. vulgaris)*	*Turbot (S. maximus)*
E	0–5	0–4	0–5	0–5
A	6–16	5–13	6–19	6–19
B	17–21	14–16	20–27	20–26
Rejected	>22	>17	>28	>27

If the industry using the QIM needs to refer the scores to the current EU classification E, A, and B, QIM-Eurofish advises the following relation between the QI scores and EU classification:

In case the average score of the assessed fish samples (3–5) per batch is between the mentioned QIM ranges, the results should be rounded off to the nearby QIM range.

Table 15.5 clearly shows that A, after the EU classification, is too broad and not detailed enough to use in electronic auctions and in production managements.

15.3 Conclusion

The QIM has been proven in the marketplace to be an easy to use, practical tool. It is widely used in research as a reference method and can be applied to a wide variety of species including crustacea and cephalopods. It is versatile and can integrate time and temperature effects since it is designed to mimic the kinetics of microbial, enzymic action, and the changes in bulk properties. Consequently the range of schemes becoming available is quite extensive. Further development of handheld devices containing these schemes and the ability to link the results with photos, traceability, authenticity, catch, and market information is required to make fuller use of the available information and to enhance electronic marketing, safety, and quality assurance procedures.

References

1. Bremner A. A Convenient easy-to-use system for estimating the quality of chilled seafood. In Scott DN and Summers C (eds.); *Proceedings of the Fish Processing Conference*, Nelson, New Zealand, 23–25 April 1985; *Fish Process. Bull.*, 7, 59, 1985.
2. Larsen EP, Hyldig G, and og Frederiksen M. Fersk fisk—Kvalitet i detailhandlen. DFU Rapport udgivet af Danmarks Fiskeriundersøgelser, Afdeling for Fiskeindustriel Forskning, Lyngby, Denmark, 1998–1999.
3. Bonilla AC, Sveinsdottir K, and Martinsdottir E. Development of quality index method (QIM) scheme for fresh cod (*Gadus morhua*) fillets and application in shelf life study. *Food Control*, 18, 352, 2007.
4. Hyldig G and Nielsen J. A rapid sensory method for quality management. In Ólafsdóttir G and others (eds.). *Methods to Determine the Freshness of Fish in Research and Industry*; *Proceedings of the Final Meeting of the Concerted Action "Evaluation of Fish Freshness" AIR3CT942283, Nantes Conference*, Nov. 12–14, International Institute of Refrigeration, Paris, France, p. 297, 1997.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

5. Warm K, Bøknæs N, and Nielsen J. Development of quality index methods for evaluation of frozen cod (*Gadus morhua*) and cod fillets. *J. Aquat. Food Prod. Technol*., 7, 45, 1998.
6. Herrero AM, Huidobro A, and Careche M. Development of quality index method for frozen hake (*M. capensis* and *M. paradoxus*). *J. Food Sci*., 68, 1086, 2003.
7. Warm K. *Sensory Quality Criteria for New and Traditional Fish Species of Relevance to Consumer Needs*. Danish Institute for Fisheries Research, Lyngby, The Royal Veterinary and Agricultural University, Copenhagen, Denmark, p. 1, 2000.
8. Larsen E, Hyldig G, Dalgaard P, Bech AC, and Østerberg C. Consumers and experts responses to fresh cod fillets. In Luten JB, Oehlenschlager J, and Ólafsdóttir G (eds.). *Quality of Fish from Catch to Consumer: Labelling, Monitoring and Traceability*. Wageningen Academic Publ., Wageningen, the Netherlands, p. 345, 2003.
9. Nielsen J, Hyldig G, and Larsen E. Eating quality of fish—A review. *J. Aquat. Food Prod. Technol*., 11, 125, 2002.
10. Larsen EP, Heldbo J, Jespersen CM, and Nielsen J. Development of a standard for quality assessment on fish for human consumption. In Huss HH, Jacobsen M, and Liston J (eds.). *Quality Assurance in the Fish Industry*. Elsevier, Amsterdam, the Netherlands, p. 351, 1992.
11. Huidobro A, Pastor A, and Tejada M. Quality index method developed for raw gilthead seabream (*Sparus aurata*). *J. Food Sci*., 65, 1202, 2000.
12. Sveinsdóttir K, Martinsdóttir E, Hyldig G, Jørgensen B, and Kristbergsson K. Application of quality index method (QIM) scheme in shelf life study of farmed Atlantic Salmon (*Salmo salar*). *J. Food Sci*., 67(4), 1570, 2002.
13. Sveinsdóttir K, Hyldig G, Martinsdóttir E, Jørgensen B, and Kristbergsson K. Development of quality index method (QIM) scheme for farmed Atlantic Salmon (*Salmo salar*). *Food Qual. Prefer*., 14, 237, 2003.
14. Nielsen D, Green D, Bolton G, Hodson R, and Nielsen J. Hybrid Striped Bass—A QIM Scheme for a Major U.S. Aquaculture Species; *Poster at First joint trans Atlantic fisheries technology conference (TAFT)*, 10–14 June 2003 Reykjavik, Iceland: *33rd WEFTA Meeting*, 2003.
15. Hyldig G and Nielsen J. QIM—A tool for determination of fish freshness. In Shahidi F and Simpson BK (eds.). *Seafood Quality and Safety. Advances in the New Millennium*. ScienceTech Publishing Company, St. John's, NL, p. 81, 2004.
16. Hyldig G and Green-Petersen DMB. Quality index Method—An objective tool for determination of sensory quality. *J. Aquat. Food Prod. Technol*., 13(4), 71, 2005.
17. Bremner HA, Olley J, and Vail AMA. Estimating time-temperature effects by a rapid systematic sensory method. In *Advances in Food Research: Seafood Quality Determination*. Elsevier Press, Amsterdam, the Netherlands, p. 413, 1987.
18. Anonymous, Council regulation (EC) No. 2406/96 of November 26, 1996, Laying Down Common Marketing Standards for Certain Fishery Products. *Official J. Eur. Commun*., No. L334, 1–14, 1996.
19. Martinsdóttir E, Sveinsdóttir K, Luten J, Schelvis-Smit R, and Hyldig G. *Sensory Evaluation of Fish Freshness. A Reference Manual for the Fish Industry*. QIM-Eurofish, the Netherlands, 2001, 2004. Available from http://www.qim-eurofish.com.
20. Andrade A, Nunes ML, and Batista I. Freshness quality grading of small pelagic species by sensory analysis. In Ólafsdóttir G and others (eds.). *Methods to Determine the Freshness of Fish in Research and Industry*; *Proceedings of the Final Meeting of the Concerted Action "Evaluation of Fish Freshness" AIR3CT942283, Nantes Conference*, Nov. 12–14, International Institute of Refrigeration, Paris, France, p. 333, 1997.
21. Barbosa A and Vaz-Pires P. Quality index method (QIM): Development of a sensorial scheme for common octopus (*Octopus vulgaris*). *Food Control*, 15, 161, 2004.
22. Baixas-Nogueras S, Bover-Cid S, Veciana-Nogues T, Nunes ML, and Vidal-Carou MC. Development of a quality index method (QIM) to evaluate freshness in Mediterranean Hake (*Merluccius merluccius*). *J. Food Sci*., 68(3), 1067, 2003.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

23. Pons-Sánchez-Cascado S, Vidal-Carou MC, Nunes ML, and Veciana-Nogués, MT. Sensory analysis to assess the freshness of Mediterranean anchovies (*Engraulis encrasicholus*) stored in ice. *Food Control*, 17, 564, 2006.
24. Massa AE, Palacios DL, Paredi ME, and Crupkin M. Postmortem changes in quality indices of ice-stored flounder (*Paralichthys patagonicus*). *J. Food Biochem*., 29, 570, 2005.
25. Lyhs U and Schelvis-Smit R. Development of a quality index method (QIM) for Maatjes Herring stored in air and under modified atmosphere. *J. Aquat. Food Prod. Technol*., 14(2), 63, 2005.
26. Vaz-Pires P and Seixas P. Development of new quality index method (QIM) schemes for cuttlefish (*Sepia officinalis*) and broadtail shortfin squid (*Illex coindetii*). *Food Control*, 17(12), 942, 2006.
27. Guillerm-Regost C, Haugen T, Nortvedt R, Carlehög M, Lunestad BT, Kiessling A, and Rora AMB. Quality characterization of farmed Atlantic Halibut during ice storage. *J. Food Sci*., 71(2), 83, 2006.
28. Bekaert K. Development of Quality Index Method scheme to evaluate freshness of tub gunard (*Chelidonichthys lucernus*). In Luten JB, Jacobsem C, Bekaert K, Sæbö A, and Oehlenschläger J (eds.). *Seafood from Fish to Dish*. Wageningen Academic Publishers, the Netherlands, p. 289, 2006.
29. Boulter M, Poole S, and Bremner A. *Australian Quality Index Manual*. Fisheries Research and Development Corporation, Canberra ACT, 2006.
30. ISO 8589. *Sensory Analysis—General Guidance for the Design of Test Rooms*, 1st edn., International Standard, Geneva, Switzerland, 1988.
31. NMKL procedure No. 12. *Guiding on Sampling*. Nordic Committee on Food Analysis, Copenhagen, Denmark, 2002. Available at http://www.nmkl.org.
32. Codex: Recommended International code of Practice for Fresh Fish CAC/RCP 9–1976Codex standards for methods of analysis and sampling, "Sampling Plans for Prepackaged Foods (AQL 6.5)," XOT 13–1969, Rome, FAO/WHO Codex. Alimentarius. Codex XOT 13–1969, 1976.
33. ISO 8586-1. *Sensory Analysis—General Guidance for the Selection, Training and Monitoring of Assessors. Part 1: Selected Assessors*, 1st edn. International Standard, Switzerland, 1993.
34. ISO 11035. *Sensory Analysis—Identification and Selection of Descriptors for Establishing a Sensory Profile by a Multi-Dimensional Approach*, 1st edn., International Standard, Geneva, Switzerland, 1994.
35. Branch AC and Vail AMA. Bringing fish into the computer age. *Food Technol. Aust*., 37, 352, 1985.
36. Heldbo, J. *Information Technology and Production Management in the White Fish Industry*. Industrial PhD thesis, Danish Institute for Fisheries Research and The Royal Veterinary and Agricultural University, Copenhagen, Denmark, 1990.
37. Jónsdóttir SM, Hyldig G, Nielsen J, Bleechmore T, and Silberg S. Rapid PC based sensory methods. *Infofish Int*., 2, 54, 1999.
38. Luten JB. Development and implementation of a computerised sensory system (QIM) for evaluating fish freshness. CRAFT FAIR CT97 9063. Final Report for the period from 01–01–98 to 31–03–00, Wageningen, the Netherlands, RIVO The Netherlands Institute for Fisheries Research, p. 18, 2000.
39. Howgate P. *Approaches to the Definition and Measurement of Storage Life of Chilled and Frozen Fish*. Torry Research Station, Aberdeen, U.K., 1985.
40. Martinsdóttir E and Blomsterberg F. Sjálfvirk ferskleikamæling með RT-gæðaflokkara 12. RIT Icelandic Fisheries Laboratories, 1987.
41. Magnússon H, Martinsdóttir E, and Steinþórsson P. Áhrif frystingar og frystigeymslu þorsks eftir þíðingu. 26. Icelandic Fisheries Laboratories REPORT no. 26, 1990.
42. Rehbein H, Martinsdóttir E, Blomsterberg F, Valdimarsson G, and Öehlenschläger J. Shelf life of ice-stored redfish, *Sebastes marinus* and *S. mentella. Int. J. Food Sci. Technol*., 29, 303, 1994.
43. Martinsdóttir E, Sveinsdóttir K, and Ólafsdóttir G. Development and Implementation of a Computerised Sensory System (QIM) for Fish Freshness. Icelandic Fisheries Laboratories Project Report 11, 2000.
44. Nielsen D and Hyldig G. Influence of handling procedures and biological factors on the QIM evaluation of whole herring (*Clupea harengus* L.). *Food Res. Int*., 37(10), 975, 2004.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

45. Huidobro A, Pastor A, Lopez-Caballero ME, and Tejada M. Washing effect on the quality index method (QIM) developed for raw gilthead seabream (*Sparus auratus*). *Eur. Food Res. Technol*., 212, 408, 2001.
46. Bremner HA, Statham JA, and Sykes SJ. Tropical species from the North-West Shelf of Australia. Sensory assessment and acceptability of fish stored on ice. *Proceedings of the Sixth Session IPFC Working Party on Fish Technology and Marketing*, Melbourne 1984 FAO, *Fish Rep*., 317(Suppl.), 41, 1984.
47. Triqui R and Bouchriti N. Freshness assessment of Moroccan Sardine (*Scardina pilchardus*): Comparison of overall sensory changes to instrumentally determined volatiles. *J. Agric. Food Chem*., 51, 7540, 2003.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 16

Sensory Descriptors

Grethe Hyldig

Contents

16.1 Introduction 285
16.1.1 Sensory Analysis 286
16.1.2 Objective and Subjective Sensory Analysis 286
16.2 The Human Senses 286
16.2.1 The Sense of Vision 286
16.2.2 The Olfactory Sense 287
16.2.3 The Sense of Touch 287
16.2.4 The Gustatory Sense 287
16.2.5 The Chemical/Trigeminal Sense 288
16.2.6 The Sense of Hearing 288
16.3 The Use of Sensory Descriptors 288
16.4 Sensory Descriptors in Seafood 291
16.4.1 Appearance 291
16.4.2 Odor 292
16.4.3 Taste/Flavor 292
16.4.4 Texture 296
References 299

16.1 Introduction

The sensory quality of seafood is influenced by the treatment and processing from harvest, through transportation, storage, and processing. Sensory analysis of seafood has therefore played a natural part of the seafood chain for years.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

16.1.1 Sensory Analysis

In sensory analysis appearance, odor, flavor, and texture are evaluated using the human senses of vision, smell, taste, touch, and hearing. Scientifically, the process can be divided into three steps: (1) detection of a stimulus by the human sense organs; (2) evaluation and interpretation by a mental process; and (3) then the response of the assessor to the stimuli.

16.1.2 Objective and Subjective Sensory Analysis

A special aspect of sensory analysis is that it can be both objective and subjective. The objective tests include discriminative (triangle test, forced choice) and descriptive (profiling, structured scaling) sensory tests. Both groups of tests are analytical measurements of the intrinsic quality of the product. The subjective tests are used for consumer testing and to measure the attitude and emotional response of the consumer toward the product. The subjective tests can be applied in the fields such as market research and product development where the consumer reaction is required.

In the objective tests, a trained panel objectively describes the attributes of products using defined sensory descriptors [1–3], whereas the subjective tests use untrained human beings (consumers) who answer subjectively, for example, how much they like/dislike a product. The objective sensory analytical methods do not depend on whether assessors like or dislike a certain item. Instead, it operates with the determining of intensities of sensory descriptors such as sweetness, amine, sourness, softness, and the like.

In the following text, the focus will be on sensory descriptors that are used in objective sensory tests.

16.2 The Human Senses

In a sensory test, the first sense that the assessor uses is the vision. The vision is used to measure the appearance such as color and texture properties. The next sense is the olfactory that are used for detecting odors. Then the assessor touches the sample, with the fingers, directly or indirectly by using a tool (e.g., spoon or fork) and in the mouth where also the tongue and lips are used to measure the texture properties. In the mouth, the sense of gestation and the trigeminal sense are used to measure the taste, the pain, and the cooling effects. During the whole assessment, the sense of hearing is used to measure the sound both outside and inside the mouth, like when a cracker is broken or during chewing.

16.2.1 The Sense of Vision

The visual sense is often equated only with color but provides also input on many appearance attributes such as size, shape, and surface structure. In particular, the visual senses can provide an early and strong expectation of the flavor and textural properties of food.

The visual receptors, the rods and cones, are located in the retina of the eye. These receptors contain light-sensitive pigments, which change shape when stimulated by light energy, leading to the generation of electrical nerve impulses that travel along the optic nerves to the brain. There are ~120 million rods in the retina. The maximum rod concentration is ~20° from the foveal area; this area is the parafovea. The 6 million cones operate at higher light intensities (levels of illumination) and provide chromatic information (color), allowing photopic vision.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The light reflected from an object, or the light passing through an object, falls on the corona, travels through the lens, and from there to the retina, where most of the light falls on a small hallow in the retina, the fovea, a small depression located in a yellow-colored spot (*macula lute*) on the retina.

The rods are capable of operating at extremely low light intensities (<1 lx). The rods yield only achromatic (black/white) information, and under low light conditions, these rods give a scotopic vision with no color perception.

The cones are concentrated on the fovea, where the highest color resolution occurs. When viewing an object, the unconscious movement of the eyes serves to bring the image of the object onto the foveal areas. The cones contain three color-sensitive pigments, each responding to red (two polymorphic variations 552 and 557 nm), green (at 530 nm), or blue light (at 426 nm) most sensitively [4,5]. People lacking one of these pigments are color-blind categories, and depending on which pigments they are missing can be classified into different groups. The genes for the more common forms of color-blindness are recessive and carried on the X chromosome. Thus, the trait is seen much more frequently with men than with women.

16.2.2 The Olfactory Sense

The odor response is much more complex. The olfactory receptors are located very high in the nasal cavity. There are several million receptors on each side of the nose, and they are highly ciliated. The function of the cilia is to greatly increase the surface area exploring the receptors to chemical stimuli. Odors are detected as volatiles entering the nasal passage, either directly via the nose or indirectly through the retronasal path via the mouth. Some 150–200 odor qualities have been recognized [6]. The odor receptors are easily saturated, and specific anosmia (blindness to specific odors) is common. It is thought that the wide range of possible odor responses contributes to variety in flavor perception.

16.2.3 The Sense of Touch

Texture is perceived by the sense of touch and comprises two components: *somesthesis*, a tactile, surface response from skin; and *kinesthesis* (or proprioception), a deep response from muscles and tendons.

The touch stimuli themselves can arise from tactile manipulation of the food with hands and fingers, either directly or through the intermediary of utensils such as a knife or a spoon. Oral contact with food can occur through the lips, the tongue, the palate, and the teeth, all of which provide textural information. For many foods, visually stimuli will generate an expectation of textural properties.

As food enters the mouth and is either bitten or manipulated between tongue and palate, changes occur to the structure of the food that strongly influence the way in which tastants and odorants are released from the food. Temperature increase (cold foods) or decrease (hot foods) and dilution by saliva are of particular importance.

16.2.4 The Gustatory Sense

Taste is defined as the response by the sense organs on the tongue and soft palate contains the taste receptors. These have been defined as five primary basic taste sensations—salt, sweet, sour, bitter, and umami.

The taste receptors are organized in groups of cells, known as taste buds, located within specialized structures called *papillae*. These are located mainly on the tip, sides, and rear upper surface of the

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

tongue. Taste buds are onion-like structures and each taste bud contains approximately 50–100 taste cells. A single taste cell may be multimodal, with several types of receptors; one type may be more active than others on that cell. Each taste receptor cell is connected through a synapse to a sensory nerve ending, which is a peripheral afferent fiber, sending the taste-coding information to the brain.

The taste buds are located on the surface of the tongue within taste papillae. On the front and edges of the tongue, there are slightly larger mushroom-shaped fungiform papillae (reddish spots). There are over 100 on each side. These papillae contain from two to four taste buds each [7,8].

Along the sides of the tongue, about two-thirds of the way back from the tip to the root several parallel grooves. These are the foliate papillae and each contains several hundred taste buds.

At the back of the tongue there are the large button-shaped bumps arranged in an inverted-V. These are circumvallate papillae, which also contain several hundred taste buds. Frequency counts of taste buds show that people with higher taste sensitivity tend to possess more taste buds [9].

Saliva plays an important part in taste function, both as a carrier of sapid molecules to the receptors and because it contains substances capable of modulating taste receptors. Saliva contains sodium and other cations, bicarbonate capable of buffering acids, and range of proteins and mucopolysaccharides that give it its slippery and coating properties.

16.2.5 The Chemical/Trigeminal Sense

The chemical sense corresponds to a pain response through stimulation of the trigeminal nerve. This effect is produced by chemical irritants such as ginger and capsaicin (from chili), of which both give a heat response, and chemicals such as menthol and sorbitol, which give a cooling response. Astringency is a chemically induced complex of tactile sensations.

16.2.6 The Sense of Hearing

Sound emission from crisp and crunchy foods has been shown to be of great importance in the perception of their texture (e.g., [10]) and to form a basis for discrimination of crisp and crunchy foods.

16.3 The Use of Sensory Descriptors

In analytical sensory studies, a trained panel objectively describes the attributes of products [11,12]. The criteria for specific sensory descriptors, the key aspects of the words, which should be considered are: (1) that the descriptors should be orthogonal; (2) that they should be based on underlying structure if it is known; (3) that the descriptors should be based on a broad reference set; and (4) that they should be precisely defined, and finally, that they should be "primary" rather than "integrated."

When developing a set of sensory descriptors that can be used for sensory characterization of a product, the process is split up in a *qualitative* and a *quantitative* part.

The *qualitative* part consisted of collecting descriptive words for appearance, odor, taste, and texture. First of all assessors suggested words and then words from literature are added to the vocabulary. The main point of the *qualitative* part is to group similar words in a mental map by the assessors with help of the panel leader. A verbal explanation of the descriptors is developed in cooperation with both the panel leaders and the panel. References of the different attributes are found. If it is necessary to reduce the vocabulary further multivariate data analysis can be used.

In the *quantitative* part, the panel is trained in use of the scale that is chosen for the sensory analysis.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

In a study of Green-Petersen et al. [13] they performed a sensory profile of the most common chilled and frozen salmon products available to consumers on the Danish market. The sensory profiling was made on 12 salmon products, varying in salmon species, origin, storage method, and time. Samples stored in ice between 7 and 16 days, frozen for 1 month or stored in modified atmosphere for 5 days all had sensory profiles dominated by sea/seaweed odor, juicy and oily texture, fresh fish oil, sweet, and mushroom flavor. The list of words from this study in the qualitative part of developing the set of sensory descriptors is shown in Table 16.1.

Table 16.1 Words from the First Session in the Qualitative Part in Developing a Set of Sensory Descriptors Used for Sensory Profiling of Salmon

Odor			
Green grass	Cucumber	Sea	Seaweed
Amine/farmyard	Sour/sour socks	Rancid	Sourish
Sickly sweet	Warm milk	Sweet	Wet dog
Caramel	Burnt	Hay/dry grass	Pleasant farmyard
Sweetness/ fermented grass	Bear and bread	Mushroom	Forest floor/earthy
Appearance			
Bright/dull	Slimy surface	Shiny	Pearl-shiny
Discoloration	Coagulated protein	Moisture in the bowl	Orange oil droplets
Oily	Salmon	Orange	Reddish
Taste/Flavor			
Warm milk	Sweetness	Fish oil/fresh nuts	Nutty
Mushroom	Sea	Sourish	Sickly sweet
Hey	Amine/farmyard	Rancid	Cooked potato
Green	Sour	Bitter	Chemical
Metal	Salty	Mealy taste	Cooked egg white
Cream	Fermented green grass	Brown soap	Cabbage/broccoli
Texture			
Fiber	Watery	Soft/firm	Dry/juicy
Fatty	Oily	Loos flakes	Flaky (firm)
Sticky	Fibrous	Grainy	Mealy

Source: Green-Petersen, D.M.B. et al., *J. Sens. Stud.*, 21, 415, 2006.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

As it can be seen the first list of words consisted of 20 words for odor, 12 for appearance, 24 for taste/flavor, and 12 for texture. Based on the criteria that the words should be relevant and discriminate clearly between the salmon samples, they should be nonredundant, and be cognitively clear to the assessors, the words were reduced and the selected descriptors for the sensory profiling are shown in Table 16.2.

Table 16.2 Sensory Descriptors Used for Sensory Profiling of Salmon

Descriptor	*Description*
Odor	
Sea/seaweed	Fresh seaweed, fresh sea
Sourish	Acidic, fresh citric acid
Sweet	Sweet
Rancid	Rancid fish, paint, varnish
Sour	Sour dishcloth/sour sock
Appearance	
Discolored	Brown or yellow spots, dark areas
Salmon color	Evaluated with a SalmoFan ruler (Roche)[a]
Texture	
Juicy	The sample's ability to hold water after 2–3 chews
Firm	Force required to compress the sample between the molars
Oily	Amount of fat coating in the mouth
Flavor	
Fresh fish oil	Fresh oil, fresh green hazelnut
Sweet	Sweet, warm milk
Sourish	Acidic, fresh citric acid
Cooked potatoes	Cooked peel potatoes
Mushroom	Mushroom flavor
Rancid	Rancid fish, paint, and varnish
Salt	Salt

Source: Green-Petersen, D.M.B. et al., *J. Sens. Stud.*, 21, 415, 2006.

[a] Evaluated with a SalmoFan ruler (Roche) on a interval scale from 20 to 34, where 20 is more light salmon color (pink) than 34.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

16.4 Sensory Descriptors in Seafood

Criteria for selection of attributes, which can discriminate between the samples, have to be relevant for the specific seafood, must discriminate clearly between the samples, must be nonredundant, and be cognitively clear to the assessors. To see if these demands are fulfilled, the sensory data can be analyzed concerning the signal to noise relation for each assessor and attribute. The signal to noise analysis can be evaluated with multivariate data analysis [14]. To be cognitively clear and to make reference samples it is good to have a definition of the sensory attribute. Reference samples for the different attributes can be found not only in seafood samples, but also in other commodities such as vegetables, e.g., cucumber and boiled potato. Another example is the sensory attribute warm milk, where only heated and not boiled milk can be used, because when boiling milk a sulfurous odor is developed.

16.4.1 Appearance

Appearance can be color/discolor and texture properties such as flaky or gaping. Flaky is assessed by pressing on the sample with a fork; if the muscle separates in flakes, the sample has a high intensity of flakiness. The fish is gaping when the muscle splits up in factions or chaps. Gaping can be seen both in raw and heat-treated fish muscle. For assessing color, it is helpful to use standards, such as the natural color system (NCS®) or for salmon the *Salmo*Fan™ lineal from Roche.

A description of the attributes is given in Table 16.3.

Table 16.3 Sensory Descriptors for Appearance

Attribute	*Definition*	*References*
Beige	Intensity of beige color	[15]
Brownish	Light brown	[16]
Brown	The brownness of the meat near the head (cross-section at cut end) of cooked shrimp	
Coagulated protein	Whitish form on top of and beside sample	[16]
	Amount of coagulation that appears on the surface of the salmon steak	[15]
Color intensity and shade	1 = white/yellow, 7 = strong red	[17]
Crumbly	Crumbliness of steak when cut with a knife	[15]
Discoloration	Uneven color distribution	[18]
Discolored	Brown or yellow spots, dark areas	[13]
Discolored	Not the natural color	[19]
Fat droplets in water	Quantity and size of fat droplets in the liquid	[18]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 16.3 (continued) Sensory Descriptors for Appearance

Attribute	*Definition*	*References*
Flacky	Visible flakiness of steak when cut with a knife	[15]
	Tissue parts into flakes by pressing with fork	[16]
	Tissue parts into flakes by pressing with fork	[19]
Grayish	Light gray	[16]
Glossiness	The amount of light reflected from the meat, from dull to glossy	[20]
Hue	From red = 1 to yellow = 9	[21,22]
	Yellow = 1, red = 9	[23]
Juicy appearance	Amount of juice that has seeped onto the plate from the salmon	[15]
Moist appearance	Visible moistness of steak when cut with a knife	[15]
Orange	Intensity of orange color in the uncut steak	[15]
Paleness	Intensity of paleness in the uncut steak	[15]
Peach	Intensity of peach color in the uncut steak	[15]
Pink	Intensity of pink color in the uncut steak	[15]
Red/orange	The redness of the surface	[20]
Separation	Oiliness of the juice seeping out of the salmon	[15]
Shiny	Gloss of tissue caused by oil	[16]
Whiteness	Intensity of white color in the uncut steak	[15]
Whitish	Not totally white	[16]
Yellow water	Degree of yellow water liquid present	[18]

Note: Only references where the evaluation of the property is described are included in the table.

16.4.2 Odor

The odor has often a higher intensity than flavor in seafood. A description of the odor attributes is given in Table 16.4.

16.4.3 Taste/Flavor

A description of the attributes for taste/flavor and aftertaste is given in Table 16.5.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 16.4 Sensory Descriptors for Odor

Attribute	*Definition*	*References*
Acid	Vinegar	[24]
Amine	A solution of trimethylamine	[25]
	Urine	[24]
	Fishy/trimethylamine	[19]
Bacon	Odor corresponding to the product	[25]
Blue cheese	Musty	[24]
Boiled corn	Sweet aroma in boiled corn	[26]
Boiled egg	Smell of boiled egg	[26]
Boiled prawn	Typical aroma in boiled prawn	[26]
Butter	Caramel	[24]
Cabbage	Gas/garlic	[24]
Canned tuna	Aroma of canned tuna	[27]
Cardboardy	Marine fish off-odor notes	[28]
Cheese	Sour feet	[24]
Cold ash	Odor of ash once the fire is out	[25]
Cooked fish	Aroma of cooked fish	[26]
	Typical aroma of cooked fish	[27]
Cooked potato	As newly cooked potato	[19]
Cucumber-like	Grated cucumber	[28]
Earthy	Intensity of any earthy/peaty odor	[15]
Farmyard	Intensity of manure/cow-dung odor	[15]
Fat	Fresh fish oil, unripe hazelnut	[29]
Fish oil	Smell of canned mackerel or sardine	[27]
Fish oil	"Fatty" odor, herring oil, and typical smell of fresh herring	[30,31]
Fish oil	Intensity of oily (fish oil) odor	[15]
Fish/herring oil	"Fatty" odor, herring oil, and typical smell of fresh herring	[30,31]
Fishy	Smell of raw not fresh fish	[27]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 16.4 (continued) Sensory Descriptors for Odor

Attribute	*Definition*	*References*
Fishy	Trimethylamine crystals (marine fish off-odor notes)	[28]
Fresh odor	The typical odor of rainbow trout, an element of fresh, and slightly acidulous odor intensifies the freshness	[32]
Fried chicken	Aroma of fried chicken	[27]
Green	Fresh green odor of soybean milk	[27]
Green aroma	Freshly cut grass	[24]
Grilled fish	Aroma of grilled fish, roasted fish oil	[27]
Ham	Cooked meat	[24]
Herring	Odor corresponding to the product	[25]
Hydrogen sulfide	Egg	[24]
Irritate	Ammonia-like	[26]
Marine/ seaweed	Fresh marine	[19]
Metallic	Warm metal, blood	[30,31]
Rancid	Rancid fish, paint, and varnish	[13,30,31]
Rotten seaweed	Putrefied seaweed	[19]
Sea/seaweed	Fresh seaweed, fresh sea	[13]
Sickly sweet	Sickly sweetness	[19]
Smokiness	Intensity of smoky odor	[29]
Sour	Sour caused by putrefaction	[19]
	Sour dishcloth/sour sock	[13]
Sourish	Acidic, acetic acid, and citric acid	[13,29–31]
Sweet	Sucrose-like	[29]
	Sweet	[13,30,31]
Wet dog	As a wet dog	[19]

Note: Only references where the evaluation of the property is described are included in the table.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 16.5 Sensory Descriptors for Flavor and Aftertaste

Attribute	*Definition*	*References*
Acidulous	Fruit-acid-like flavor	[33]
Amine	Fishy/trimethylamine	[19]
Bitter	Quinine-/or caffeine-like	[16,19,20,29]
Chicken-like aftertaste	Intensity of chicken-like aftertaste	[15]
Chemical	Aromatic associated with lotion and cleanser	[34]
Cooked potato	As newly cooked peeled potatoes	[13,19]
Cooked shrimp	The flavor associated with cooked shrimp	[20]
Dried sea mussel	Aromatics associated with dried sea mussel	[34]
Dried shrimp	Aromatics associated with crustacean such as dried shrimp	[34]
Earthy aftertaste	Intensity of earthy aftertaste	[15]
Earthy flavor	Intensity of any earthy/peaty flavor	[15]
Farmyard flavor	Intensity of manure/cow-dung flavor	[15]
Fatty flavor	Impression of fatness perceived as aromatic notes and mouth coating film	[35]
Fishy flavor	Intensity of any other fish-like flavors	[15]
Fresh fish oil	Fresh oil, fresh green hazelnut	[13]
Fresh taste	The typical taste of rainbow trout. In this investigation, the typical taste was scored after the sample had been masticated five times. As element of fresh, slightly acidulous taste intensifies the freshness	[32]
Herring	Typical taste of fresh herring	[30,31]
Iodine aftertaste	Aftertaste associated with the chemical iodine	[20]
Marine	Fresh marine	[16]
Metallic	Flavor associated with metal	[18]
	Warm metal, blood	[19,29–31]
Metallic aftertaste	Intensity of metallic aftertaste	[15]
Monosodium glutamate (MSG)	Fundamental taste sensation of which monosodium glutamate or other nucleotides are typical	[34]
Mushroom	Raw mushroom flavor	[13,19]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 16.5 (continued) Sensory Descriptors for Flavor and Aftertaste

Attribute	*Definition*	*References*
Musty	Flavor associated with damp earth	[18]
Oily	Intensity of fish oil flavor	[15,18]
	Fresh fish oil, unripe hazelnut	[29]
Oily aftertaste	Intensity of fish oil aftertaste	[15]
Rancid	Paint, varnish	[30,31]
	The atypical taste associated with oxidized fat	[32]
	Rancid fish, paint, and varnish	[13,30,31]
Salmon-like flavor	Intensity of distinctive salmon-like flavor	[15]
Salty	Intensity of salt-like flavor	[15,20]
	Typical taste of salt, seawater	[29–31]
	The taste on the tongue associated with sodium ions	[34,35]
Smokiness	Intensity of smoky flavor	[15,29]
Sourish	Acidic, acetic acid, and citric acid	[13,30,31]
	Sourish like in fruit or as fresh fruit acids	[19,29]
Sweet	Sweet as in warm milk	[13,30,31]
	Sucrose-like	[16,19,20,29,34]
Sweet/fresh	Characteristic flavor of cooked Arctic char fillets	[18]
Time	Time when aftertaste starts	[15]

Note: Only references where the evaluation of the property is described are included in the table.

16.4.4 Texture

Texture is by definition a sensory parameter and only a human being can perceive, describe, and quantify texture adequately. However, texture is very difficult to evaluate due to its complexity. In many cases, several terms are used to describe the same characteristics. In other cases, the same term is used to describe several characteristics. Moreover, the same word may have different meanings to different people [36]. Therefore, the use of sensory texture profiling requires highly trained assessors [6,37]. Sensory perception of texture has been thoroughly reviewed by Jack et al. [38]. The best way to get a "full picture" of the texture is by the Texture Profile Method [39–42]. A texture profile is defined as the sensory analysis of the texture complex of a food in terms of its mechanical, geometrical, and compositional (fat and moisture) characteristics, the degree of each trait present, and the order in which they appear from the first bite through complete mastication [43].

In Table 16.6 there is a long list of words used in the literature for describing texture properties.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 16.6 Sensory Descriptors for Texture

Attribute	*Definition*	*References*
Adhesiveness	Degree to which the sample sticks to the mouth surface	[44]
	Force required to remove the material that adheres to the mouth during the normal eating process	[45]
Astringency	The feeling which shrivels the tongue-associated with tannin or alum	[34]
Chewiness	The time required to masticate the sample to a consistency acceptable for swallowing	[20]
Cohesiveness	The extent to which a material can be deformed before it ruptures	[46]
	Degree to which the sample deforms before it ruptures during a bite between the molar teeth	[44]
	Degree to which a substance is compressed between the teeth before it breaks	[45]
Crispness	The amount of force exerted during first incisor bite that generates a high pitched sound	[20]
Elasticity	The ability of the material to return to its original shape after deformation. Judged by compressing the substance slightly between the molars, or between the tongue and the palate, and noting to what extent the material returns to its original shape	[46]
Elasticity	The ability of the sample to regain its form after the first compression by the molars	[30,31]
Fatty mouth feel	Amount of fat coating the mouth surfaces after three chews	[30,31]
Fibrous	The presence of individual muscle fibers in the shrimp meat	[20]
Firm	The force required to compress between the tongue and the palate (first bite/first chew)	[19]
	Force required to compress the sample between the molars	[13]
Firmness	The effort to bite through the fish sample with the front teeth	[47,48]
	The force required to compress the sample between the molar teeth	[30,31,44]
	The force required to compress the material between the molars, or between the tongue and the palate	[46]
	The amount of force needed to deform the head-end of the shrimp meat by first biting through skin with incisors, then chewing with molars (skin toward molars)	[20]

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 16.6 (continued) Sensory Descriptors for Texture

Attribute	*Definition*	*References*
Grainy	The amount of small, rounded particles	[19]
Gritty	Heterogeneity. Amount of particles in the sample after three chews	[30,31]
Hardness	Resistance to breakdown on chewing to a state suitable for swallowing	[46]
	Force required to compress a substance between molar teeth (in the case of solids) or between the tongue and the palate (semisolids)	[45]
	The perceived force required to compress the sample using the molar teeth	[49]
	Chewing with molars	[48]
	Force required to bite the shrimp between second and third segment with incisors	[50]
	Compress the sample between the molar teeth and the release pressure	[51]
Juicy	Amount of wetness	[19]
	The sample's ability to hold water after two to three chews	[13,30,31]
Juiciness	The amount of moisture to masticate the sample to a consistency acceptable for swallowing	[20]
	Water release during chewing	[35]
Oiliness	Degree to which oil is perceived after chewing	[29]
Oily	Amount of fat coating in the mouth	[13]
Sliminess	The feeling of a slimy film in the mouth	[20]
Soft	Resistance to a very slight opening and shutting of the jaws	[52]
	Force required to compress the samples	[16]
Springiness	Degree to which a product returns to its original shape once it has been compressed between the teeth	[45]
	Degree to which the sample rapidly returns to its original shape after a partial deformation between the molar teeth	[44]
Tenderness	Resistance to breakdown in substructures when compressing between the tongue and the palate	[52]

Note: Only references where the evaluation of the property is described are included in the table.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

References

1. ISO 3972. Sensory analysis—Methodology—Method of investigating sensitivity of taste. Reference number ISO 3972: 1991 (E).
2. ISO 8586-1. *Sensory Analysis—General Guidance for the Selection, Training and Monitoring of Assessors—Part 1: Selected Assessors*. International Organization for Standardization, Geneva, Switzerland, 1993.
3. ISO/DIS 13299.2. Sensory analysis—Methodology—Guidance for establishing a sensory profile. ISO, Denmark, 1998.
4. Mebs SL and Nathans J. Absorption spectra of human cone pigments. *Nature*, 356, 433, 1992.
5. Mebs SL and Nathans J. Role of hydroxyl-bearing amino acids in differently tuning the absorption spectra of the human red and green cone pigments. *Photochem. Photobiol*., 58, 706, 1993.
6. Meilgaard M, Civille GV, and Carr BT. *Sensory Evaluation Techniques*, 4th edn., CRC Press Ltd., London, U.K., 2006.
7. Arvidson K. Location and variation in number of taste buds in human fungiform papillae. *Scand. J. Dental Res.,* 87, 435, 1979.
8. Miller IJ and Bartoshuk LM. Taste perception, taste bud distribution and spatial relationships. In T.V. Getchell, R.L. Doty, L.M. Bartoshuk, and J.B. Snow, eds. *Smell and Taste in Health and Disease*. Raven, New York, p. 205, 1991.
9. Bartoshuk LM, Duffy VB, and Miller IJ. PTC/PROP tasting: Anatomy, psychophysics and sex effects. *Physiol. Behav*., 56, 1165, 1994.
10. Vickers ZM. Sound perceptions and food quality. *J. Food Qual*., 14(1), 87, 1991.
11. ISO 11035. *Sensory Analysis—Identification and Selection of Descriptors for Establishing a Sensory Profile by a Multidimensional Approach*. International Organization for Standardization, Geneva, Switzerland, 1994.
12. ISO 5492. *Sensory Analysis—Vocabulary*. International Organization for Standardization, Geneva, Switzerland, 1992.
13. Green-Petersen DMB, Nielsen J, and Hyldig G. Sensory profiling of the most common salmon products on the Danish market. *J. Sens. Stud*., 21, 415, 2006.
14. Thybo AK and Martens M. Analysis of sensory assessors in texture profiling of potatoes by multivariate modelling. *Food Qual. Prefer.,* 11, 283, 2000.
15. Farmer LJ, McConnell JM, and Kilpatrick DJ. Sensory characteristic of farmed and wild Atlantic salmon. *Aquaculture*, 187, 105, 2000.
16. Warm K, Nielsen J, and Hyldig G. Sensory quality criteria for five fish species. *J. Food Qual*., 23, 583, 2000.
17. Sivertsvik M, Rosnes JT, Vorre A, Randell K, Ahvenainen R, and Bergslien H. Quality of whole gutted salmon in various bulk packages. *J. Food Qual*., 22, 387, 1999.
18. Ginés R, Valdimarsdottir T, Sveinsdottir K, and Thorarensen H. Effect of rearing temperature and strain on sensory characteristics, texture, colour and fat of Arctic charr (*Salvelinus alpinus*). *Food Qual. Prefer*., 15, 177, 2004.
19. Larsen E, Hyldig G, Dalgaard P, Bech AC, and Østerberg C. Consumers and experts responses to fresh cod fillets. In Luten, J.B., Oehlenschlager, J., and Ólafsdóttir, G. (eds.) *Quality of Fish from Catch to Consumer: Labelling, Monitoring and Traceability*. Wageningen Academic Publ., Wageningen, The Netherlands, 2003, p. 345.
20. Erikson MC, Bulgarelli MA, Resurreccion AVA, Vendetti RA, and Gates KA. Sensory differentiation of shrimp using a trained descriptive analysis panel. *LWT*, 40, 1774, 2007.
21. Einen O and Skrede G. Quality characteristics in raw and smoked fillets of Atlantic salmon, *Salmo salar*, fed high-energy diets. *Aquacul. Nutr*., 4, 99, 1998.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

22. Hemre G-I, Karlsen Ø, Eckhoff K, Tveit K, Mangor-Jensen A, and Rosenlund G. Effect of season, light and diet on muscle composition and selected quality parameters in farmed Atlantic cod, *Gadus morrhua* L. *Aquacul. Res*., 35, 683, 2004.
23. Rørå AMB, Kvåle A, Mørkøre T, Rørvik KA, Stein SS, and Thomassen MS. Process yield, colour and sensory quality of smoked Atlantic salmon (*Salmo salar*) in relation to raw material characteristics. *Food Res. Int*., 31, 601, 1998.
24. Stohr V, Joffraud JJ, Cardinal M, and Leroi F. Spoilage potential and sensory profile associated with bacteria isolated from cold-smoked salmon. *Food Res. Int*., 34, 797, 2001.
25. Cardinal M, Gunnlaugsdottir H, Bjoernevik M, Ouisse A, Vallet JL, and Leroi F. Sensory characteristic of cold-smoked Atlantic salmon (*Salmo salar*) from European market and relationships with chemical, physical and microbiological measurements. *Food Res. Int*., 37, 181, 2004.
26. Morita K, Kubota K, and Aishima T. Sensory characteristics and volatile components in aroma of boiled prawns prepared according to experimental designs. *Food Res. Int*., 34, 473, 2001.
27. Morita K, Kubota K, and Aishima T. Comparison of aroma characteristics of 16 fish species by sensory evaluation and gas chromatographic analysis. *J. Sci. Food Agricul*., 83, 289, 2003.
28. Hong LC, Leblanc EL, Hawrysh ZJ, and Hardin RT. Quality of Atlantic mackerel (*Scomber scombrus* L.) fillets during modified atmosphere storage. *J. Food Sci*., 61, 646, 1996.
29. Vogel BF, Ng YY, Hyldig G, Mohr M, and Gram L. Potassium lactate combined with sodium diacetate can inhibit growth of *Listeria monocytogenes* in vacuum-packed cold-smoked salmon and has no adverse sensory effects. *J. Food Prot*., 69, 2134, 2006.
30. Nielsen D, Hyldig G, Nielsen HH, and Nielsen J. Sensory properties of marinated herring (*Clupea harengus*)—Influence of fishing ground and season. *J. Aquat. Food Prod. Technol*., 13, 3, 2004.
31. Nielsen D, Hyldig G, Nielsen J, and Nielsen HH. Sensory properties of marinated herring (*Clupea harengus*) processed from raw material from commercial landings. *J. Sci. Food Agricul*., 85(1), 127, 2005.
32. Johansson L, Kiessling A, Kiessling K-H, and Berglund L. Effects of altered ration levels on sensory characteristics, lipid content and fatty acid composition of rainbow trout (*Oncorhynchus mykiss*). *Food Qual. Prefer*., 11, 247, 2000.
33. Einen O and Thomassen MS. Starvation prior to slaughter in Atlantic salmon (*Salmo salar*). II. Muscle composition and evaluation of freshness, texture and colour characteristics in raw and cooked fillets. *Aquaculture*, 169, 37, 1998.
34. Kang M-W, Chung S-J, Lee H-S, Kim Y, and Kim K-O. The sensory interactions of organic acids and various flavors in *Ramen* soup systems. *J. Food Sci*., 72(9), 639, 2007.
35. Turchini GM, Moretti VM, Mentasi T, Orban E, and Valfré F. Effects of dietary lipid source on fillet chemical composition, flavour volatile compounds and sensory characteristics in the freshwater fish tench (*Tinca tinca* L.). *Food Chem*., 102, 1144, 2007.
36. Szczesniak AS. Classification of textural characteristics. *J. Food Sci*., 28, 385, 1963.
37. Barroso M, Careche M, and Borderías AJ. Quality control of frozen fish using rheological techniques. *Trends Food Sci. Technol*., 9, 223, 1998.
38. Jack FR, Paterson A, and Piggott JR. Perceived texture: Direct and indirect methods for use in product development. *Int. J. Food Sci. Technol*., 30, 1, 1995.
39. Johnson EA, Peleg M, Sawyer FM, Segars RA, and Cardello A. Mechanical methods of measuring textural characteristics of fish flesh. *Refrigeration Sci. Technol*., 4, 93, 1981.
40. Bourne MC. Texture profile analysis. *Food Technol*., 22, 62, 1978.
41. Breene WM. Application of texture profile Analysis to instrumental food texture evaluation. *J. Texture Stud*., 6, 53, 1975.
42. Friedman HH, Whitney JE, and Szczesniak AS. The texturometer—A new instrument for objective texture measurement. *J. Food Sci*., 28, 390, 1963.
43. Brandt MA, Skinner EZ, and Coleman JA. Texture profile method. *J. Food Sci*., 28, 404, 1963.
44. Hamann DD and Webb NB. Sensory and instrumental evaluation of material properties of fish gels. *J. Texture Stud*., 10, 117, 1979.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

45. Sánchez MT. Food texture: Concept and measurement. *Alimentaria*, 272, 29, 1996.
46. Borderias AJ, Lamua M, and Tejada M. Texture analysis of fish fillets and minced fish by both sensory and instrumental methods. *J. Food Technol*., 18, 85, 1983.
47. Hurling R, Rodell JB, and Hunt HD. Research note: Fiber diameter and fish texture. *J. Texture Stud*., 27, 679, 1996.
48. Iseya Z, Sugiura S, and Sarki H. Procedure for mechanical assessment of texture change in dried fish meat. *Fisheries Sci*., 62, 772, 1996.
49. Cardello AV, Sawyer FM, Maller O, and Digman L. Sensory evaluation of the texture and appearance of 17 species of North Atlantic fish. *J. Food Sci*., 47, 1818, 1982.
50. Gundavarapu S, Hung Y-C, and Reynolds AE. Consumer acceptance and quality of microwave-cooked shrimp. *J. Food Qual*., 21, 71, 1998.
51. Leblanc RJ and Leblanc EL. Effect of retort process time on the physical and sensory quality of canned lobster (*Homarus americanus*) meat. *J. Food Process. Preserv*., 14, 345, 1990.
52. Schubring R and Oehlenschläger J. Comparison of the ripening process in salted Baltic and North Sea herring as measured by instrumental and sensory methods. *Z. Lebensm. U. Forsch. A*, 205, 89, 1997.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 17

Sensory Aspects of Heat-Treated Seafood

Grethe Hyldig

Contents

17.1 Introduction 304
17.2 Seafood 304
17.2.1 The Anatomy of Shellfish 304
17.2.2 The Anatomy of Fish 304
17.2.3 Difference between Fish Species and between Individuals 305
17.2.4 Handling of Seafood 306
17.3 Sensory Analysis of Seafood 306
17.3.1 Assessors 307
17.3.2 Sessions 307
17.3.2.1 Test Room 307
17.3.2.2 Scales 308
17.3.2.3 Between Samples 309
17.3.3 Preparation of Heat-Treated Seafood Samples 309
17.3.3.1 Fish Samples Heat Treated in Oven 309
17.3.3.2 Fish Samples Cooked in Water Bath 309
17.3.3.3 Fish Broth 310
17.3.3.4 Prawns and Shrimps 310
17.3.3.5 Prawns Broth 310
17.3.4 Sensory Attributes 310
17.4 Examples of Sensory Characterization of Seafood 310
References 314

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

17.1 Introduction

Sensory analysis plays an important role in quality control and quality assurance in the fish sector. To a certain extent sensory analysis is also used in product development and optimization.

Both objective and subjective sensory testing are used. The objective tests include discriminative (triangle test, forced choice) and descriptive (profiling, structured scaling) sensory tests. Both groups of test are analytical measurements of the intrinsic quality of the product, whereas the affective (subjective test) methods are used for consumer testing and to measure the attitude and emotional response of the consumer toward the product. All these methods are used in the seafood chain.

Descriptive sensory analysis such as profiling can be used to characterizing "postmortem changes" of all kind of seafood. Descriptive testing provides quantitative data and can both be very simple and used for assessment of a single attribute, or more complex and give a total characterization of sensory quality. Several conditions are unique for objective sensory profile of seafood and will be described in the following text.

17.2 Seafood

17.2.1 The Anatomy of Shellfish

Shellfish is a broad term for all aquatic animals that have a shell of some kind. Both saltwater and freshwater invertebrates are considered shellfish. "Shellfish" is a misnomer, because these invertebrates are definitely not fishes. The term "finfish" is sometimes used to distinguish ordinary (vertebrate) fish from shellfish. Shellfish is separated into two basic categories—crustaceans and mollusks. Crustaceans have elongated bodies and jointed soft (crustlike) shells.

The crustacean family includes crabs, crayfish, barnacles, lobster, prawns, and shrimps.

Mollusks are invertebrates with soft bodies covered by a shell of one or more pieces. Mollusks are further divided into gastropods, bivalves, and cephalopods. Gastropod is often referred to as a "univalve," a gastropod can be any of several mollusks with a single (univalve) shell and single muscle. Among the more common gastropods are the abalone, limpet, periwinkle, snail, and whelk.

Bivalve is any soft-bodied mollusk, such as a clam, scallop, oyster, or mussel, which has two shells hinged together by a strong muscle. Cephalopod is a class of mollusk that includes the octopus, squid, and cuttlefish. It is the most biologically advanced of the mollusks. All cephalopods share two common characteristics—tentacles attached to the head, and ink sacs, which they use to evade their predators.

The sensory quality of shellfish can vary considerably according to season, fishing ground, farming conditions, stress, and the harvesting conditions.

17.2.2 The Anatomy of Fish

Fish (vertebrae) have a backbone composed of segments (vertebrae)—and a cranium covering the brain. The backbone runs from the head to the tail. The vertebrae are extended dorsally to form neural spines, and in the trunk region, they have lateral processes that bear ribs. The ribs are cartilaginous or bony structures in the connective tissue between the muscle segments. Usually, there are also a corresponding number of false ribs or "pin bones" extending more or less horizontally into the muscle tissue. These bones have to be removed if a bone free fillet is the goal.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Fish has muscle cells running in parallel and connected to sheaths of connective tissue (myocommata) anchored to the skeleton and the skin. The bundles of parallel muscle cells are called myotomes. The myocommata run in an oblique pattern perpendicular to the long axis of the fish, from the skin to the spine. This anatomy is ideally suited for the flexing muscle movements necessary for swimming through the water. All muscle cells extend the full length between two myocommata, and run parallel with the longitudinal direction of the fish. The muscle mass on each side of the fish makes up the fillet, of which the upper part is termed the dorsal muscle and the lower part the ventral muscle.

17.2.3 Difference between Fish Species and between Individuals

The variation in the chemical composition of fish is closely related to feed intake, migratory swimming, and sexual changes in connection with spawning. Fish will have starvation periods for natural or physiological reasons (such as migration and spawning) or due to external factors such as shortage of food. Fish raised in aquaculture may also show variation in chemical composition, but in this case, several factors can be controlled, and the chemical composition may be predicted. To a certain extent, the fish farmer is able to design the fish by selecting the farming conditions. It has been reported that factors such as feed composition, environment, fish size, and genetic traits all have an impact on the composition and quality [1–3].

There is not only difference between species, but also a considerable variation between individuals. These variations must be taken into account when setting up experiments using sensory analysis to characterize fish and fish products. In farmed salmon (*Salmo salar*), e.g., the lipid content can differ from 10% to 19% lipid in salmon from the same farm.

Moreover, for herring there is a wide variation in lipid content within catches. A single catch can contain herring (*Clupea harengus*) with lipid content ranging from 1% to 25%. This variation is due to heterogeneity caused by mixing between stocks [4].

The lipid fraction is the component showing the greatest variation. Often, the variation within a certain species will display a characteristic seasonal curve with a minimum around the time of spawning.

Although the protein fraction is rather constant in most species, variations have been observed such as protein reduction occurring in salmon during long spawning migrations [5,6] and in Baltic cod during the spawning season [7].

Fish is often divided into lean and fatty fish. A possible method for discriminating between lean and fatty fish species is to term fish that store lipids only in the liver as lean, and fish storing lipids in fat cells distributed in other body tissues as fatty fish. Typical lean species are the bottom-dwelling ground fish like cod fish and flat fish species. The lipid content of fillets from lean fish is low and stable whereas the lipid content in fillets from fatty species varies considerably. In many species most of the muscle is white or has a light color, but many fish species have a certain amount of dark tissue of a brown or reddish color. The dark muscle is located just under the skin along the body side. A typical pelagic fish as herring will contain ~25% of dark muscle required for prolonged aerobic muscle activity. The proportion of dark muscle varies with the activity of the fish. The larger dark muscle is found in fish that are more active. There are many differences in the chemical composition of the two muscle type, e.g., higher levels of lipids and myoglobin in the dark muscle. From a technological point of view, the high lipid content of dark muscle is important and can give high intensities of desirable sensory notes, but also a shorter shelf life due to lipid oxidation resulting in rancid and sour notes among others. Demersal species such as cod

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

has a white flaky and tender muscle; textural changes such as toughness and chewiness pose the most noticeable problem during storage. The white muscle is used for quick attacks or escapes—not for long destinations.

Whether a fish is lean or fatty the actual fat content is important for the technological characteristics postmortem. The changes taking place in fresh lean fish may be predicted from the knowledge of biochemical reactions in the protein fraction, whereas in fatty species the changes in the lipid fractions have to be taken into account. The implication may be that the storage time is reduced due to lipid oxidation, or special precautions have to be taken to avoid this complication.

The reddish meat color found in salmon and sea trout does not originate from myoglobin but is due to the red carotenoid, astaxanthin. The function of this pigment has not been clearly established, but it has been proposed that the carotenoid may play a role as an antioxidant.

17.2.4 Handling of Seafood

"Rigor mortis" begins immediately or shortly after death if the fish is starved and the glycogen reserves are depleted, or if the fish is stressed. The technological significance of rigor mortis is of major importance, when the fish is filleted before or in "rigor." In rigor, the fish body will be completely stiff; the filleting yield will drop significantly, and rough handling can cause gaping in the fillets. If the fillets are removed from the bone "prerigor" the muscle can contract freely and the fillets will shorten following the onset of rigor. Dark muscle may shrink up to 52% and white muscle up to 15% of the original length [8]. If the fish is cooked prerigor the texture will be very soft and pasty. In contrast, the texture is tough but not dry when the fish is cooked in rigor. "Postrigor" the flesh will become firm, succulent, and elastic.

In some fisheries, bleeding of the fish is very important as a uniform white fillet is desirable. Discoloration of the fillet may also be a result of rough handling during catch and catch handling while the fish is still alive. Physical rough handling in the net (long trawling time, very large catches) or on the deck (stepping on the fish or throwing boxes, containers, and other items on top of the fish) may cause bruises, rupture of blood vessels, and blood oozing into the muscle tissue (hematoma).

Shellfish is harvested and stored alive or shortly after harvesting processed and frozen. Shellfish acts as a filter and therefore contain mud and bacteria; hence, they should be washed in clean seawater as soon as they are harvested. After being washed, shellfish should be packed and kept cool under storage and transport.

17.3 Sensory Analysis of Seafood

Objective descriptive sensory requires a tested and trained panel together with a test room [9,10]. In the sensory method, profiling, a series of attributes will be developed to describe the sensory characteristics describing appearance, smell, taste, and texture (see the previous chapter). The panel must be trained in identification of the attributes and furthermore the panel must be trained in using a scale for describing the intensity of the attributes. In a session, the samples will be served in random order, and between the samples, there will be served something that can be used to clean the mouth.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

17.3.1 Assessors

When selecting and training assessors for sensory analysis of seafood, it is very important to be remembered that, some people cannot taste rancid flavor, iodine, geosmin, and some have a very low response to cold-storage flavor and rancidity. Moreover, some people are allergic or hypersensitive to different fish proteins, shellfish, or histamine.

Special care must be taken to a number of relations. The assessors must not be afraid of fish bones. Some flavors are very special such as iodine (from bromophenols) and muddy (from geosmin or 2-methyl-*iso*-borneol) must be known to the assessors. Further, there might be considerable differences between the individual seafood, and it can be a challenge to have the homogeneous samples and it is even more complicated to get replicates for a panel of 12. In all cases, the assessors require intensive training and a detailed briefing before each session.

Interpretation of the stimulus and response must be trained very carefully in order to receive objective responses. It is very easy—as an example—to give an objective answer to the question: is the fish in rigor (completely stiff), but more training is needed if the assessor has to decide whether the fish is post- or prerigor.

Training is essential as it provides all assessors with a common vocabulary, thus decreasing the risk of different quantitative and qualitative interpretation of descriptors [9,11]. Furthermore, continuous training during long-term projects, preferably using reference material, can reduce the risk of drifting. If the training is interrupted, the assessors might forget descriptor meanings and/or rating levels with time. The performance of a sensory panel has to be evaluated and calibrated just as any other instrument in the laboratory in order to give reliable results. If this is not the case, the risk of drawing wrong conclusions from the experiment is high.

By serving the same product as a reference before each session, assessors can recapitulate the descriptors easily and can recalibrate their evaluations to the same scale. The additional use of coded reference samples served together with the actual samples makes it possible to monitor the performance of the panel. Multivariate data analysis allows for quick calculations and results are easily interpreted with the visual layout [12].

17.3.2 Sessions

It is important to serve the heated samples hot and in containers with lids. In this way, the assessors get the full impression of the odor just after opening the lid. When the samples are cooked in plastic bags odor attributes are assessed immediately after opening the vacuum bags, while flavor and texture are evaluated after removing the samples from the bag [3,13]. Each assessor evaluated the samples in replicate and all the samples must be served to each assessor in a randomized order to minimize possible carry-over effects between the samples.

The number of samples for each session depends on the number of attributes and the type of the sample. For the cooked samples without any spices added, the assessors can evaluate ~10 attributes in six samples within a session. If there are many attributes, it is necessary to cut down the number of samples in each session. It is important to give the assessors a short break, 1–3 min, between each sample.

17.3.2.1 Test Room

There are international and national standards and guidelines for the design and construction of sensory assessment rooms [9–11,14,15].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

In quality control procedures, special facilities or rooms are preferred for sensory evaluation, but it is not always possible. In industry and auctions, the testing area should adhere to the ISO 8589 standard as closely as possible.

- The test room must be a separate room and it must be easy accessible to the assessors. There must be a booth for each assessor.
- Temperature must be constantly around 20°C–24°C.
- Noise level shall be kept to a minimum; during a session, the assessors must be able to work without any interruption.
- Free of any foreign odor. As a minimum, there must not be any waste or other matter, or operation with a strong smell nearby. It must be possible to change the air in the test room.
- Testing area must be easy to clean and disinfect. Regular cleaning and disinfecting shall take place. It must be ensured that the cleaning agents used do not leave odors in the testing area. The colors in the test room must be light gray such as NCS-S1002Y-S3002Y.
- Lighting is very important. It is preferable to have real daylight according to ISO standard [10] but as a minimum, there should be an intensity of 600–1500 lx/m^2.
- No eating, drinking, or smoking shall be allowed in the testing area.

17.3.2.2 Scales

Different type of scales can be used, but the most common is the line scale and the nine-point scale. For assessing the color it is helpful if standards are used, such as the natural color system (NCS®).

The most commonly used scale (Figure 17.1A) is the 15 cm unstructured line scale, with two anchor points: "little" and "much" of attribute intensity, e.g., placed 1.5 cm and 13.5 cm from the endpoint of the scale [16–23].

An intensity scale from 0 to 100 (Figure 17.1B) is also suggested [24–26]. Here is 0 defined as minimum mark or nothing of the attribute and 100 as the maximum mark of the attribute. Others are using a nonstructured continuous line scale of different length: 8 cm [27], 10 cm [28–30], or 15 cm [31–34].

The nine-point scale (Figure 17.1C) can be either an continuous intensity scales going from 0 (low intensity) to 9 (high intensity) [35,36] or a line scale where the responses are transformed into numbers after assessment, where 1 equals no intensity and 9 equals high intensity [2–3,13,32,37].



Figure 17.1 Intensity scales. (A) Unstructured line scale with two anchor points; (B) scale from 0 to 100; (C) nine points going from 0 to 9.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

17.3.2.3 Between Samples

Different cleaning items can be used to dissipate residual flavors and particles between evaluations depending on the samples.

Tap water can be used if it is not too bitter and it should be served at room temperature together with unsalted crackers or crisp bread. The tap water can be filtered through a domestic water filter to remove any extraneous flavors [38], but also distilled water combined with unsalted crackers can be used [39].

If the samples have off-flavor or taint, some acidic solution can be used in combination with a longer break between the samples. Bett et al. [40] used unsalted soda crackers and citric acid (0.03%) solution as "palate cleansers." Peeled cucumber in slices can be used together or instead of crackers.

17.3.3 Preparation of Heat-Treated Seafood Samples

Sampling for sensory analysis must be as representative as possible and therefore consideration must be given not only to how and where the sample is cut, but also to the effect of the chosen method for heat treatment. The preparation must have a minimal sensory impact of the "innate" characteristics of the samples. Different types of seafood products demand different sample preparation. The optimal amount of seafood prepared for each assessor is a portion size of 30–100 g. All the samples must be marked individually with three-digit or four-digit codes. The samples must be placed in individual containers such as porcelain bowls and covered with porcelain lids.

For fat fish species, it is important to consider whether the samples should be with or without the skin. As the dark muscle is right under the skin and if the fillet are skinned some of the dark muscle will be removed. This process can exercise an influence on rancid flavor due to the high lipid content in the dark muscle. If the samples for replicates for each assessor are taken from the same position of each fillet, it is possible to have real replicate and thereby identify if there is any differences between assessors or between fillets from different parts of the fish. If the texture is of no importance, it is possible to make minced fish samples to eliminate the differences between individuals.

For shellfish, there can be some special conditions due to sample size. For example, shrimp can be very different in size; some are large enough to be assessed in one "mouthful," but others are so small that several shrimps are needed for one "mouthful." Concerning the variation between individuals, it can be an advance to ask the assessors to take three or four shrimps, depending of the size, at a time.

17.3.3.1 Fish Samples Heat Treated in Oven

The samples from fish species such as cod (*Gadus morhua*), salmon (*S. salar*), and saithe (*Pollachius virens*) are cut from the loin part in $8 \times 4 \times 2$ cm pieces corresponding to approximately 75 g. Smaller fish species such as rainbow trout (*Oncorhynchus mykiss*), herring (*C. harengus*), and plaice (*Pleuronectes platessa*) require a whole fillet, which gives the samples of ~40–50 g for plaice and herring and approximately 75–100 g for rainbow trout. The samples are heated, e.g., in a convection oven in their own juice at 100°C to an internal temperature of 70°C.

17.3.3.2 Fish Samples Cooked in Water Bath

Fish can also be cooked in a water bath as suggested by Bjerkeng et al. [13], Nortvedt and Tuene [3], Sivertsvik et al. [41], and Hemre et al. [42]; 1.5 cm thick cutlets of salmon (*S. salar*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and cod (*G. morhua*) or loin part of Atlantic halibut (*Hippoglossus hippoglossus* L.) fillets were packaged in diffusion tight plastic bags under vacuum and cooked in water bath at 85°C for 15 min or at 70–72°C for 1 h without salt or other spices.

17.3.3.3 Fish Broth

For very different fish species, it can be an advantage to have a sample preparation where the fish are cut into small pieces and boiled to a broth. This was carried out in the study of Ref. [34]. All the species except loach were gutted, and tuna and swordfish were also skinned. Small fish species such as banded blue-sprat, sardine, loach, pond smelt, and goby were boiled completely, while the others were cut into 3–4 cm lengths before boiling as in ordinary domestic cooking. Each sample (200 g) was placed in a three-necked separable 31 round flask along with 200 mL of boiling water, than heated with refluxing for 30 min by a mantle heater. The fish broth (350 mL) obtained after filtering the boiled mixture through three layers of cotton gauze was divided into 35 mL aliquots in 50 mL glass vials. Fish broth (35 mL) prepared from 20 g fish was placed in a 260 mL disposable plastic cup, covered with a plastic Petri dish, and served to the panelists at 40°C.

17.3.3.4 Prawns and Shrimps

Frozen prawns and shrimps must either be thawed for 1 h at room temperature before cooking or added directly to the boiling water, depending on the size. The cooking time in boiling fresh water is 3 min. After cooking the prawns/shrimps are drained, cooled with cold water, peeled, and held at 7°C–10°C until evaluation [16,31,37].

17.3.3.5 Prawns Broth

If a sensory profiling of whole prawn is required, it is possible to make a broth where both shell and the meat are assessed at the same time.

Morita et al. [28] thawed frozen prawns (kuruma prawns (*Penaeus monodon*) and black tiger prawns (*P. monodon*)) with running water, 190 g meat and/or 30 g shell were cut into 1 cm^2 pieces and after adding 400 mL of deionized distilled water, the mixture boiled for 30 min. Broth was obtained by filtering the boiled mixture through three layers of cotton gauze. The broth was divided into 35 mL each and preserved in 50 mL glass vials at −50°C until performing sensory evaluation.

17.3.4 Sensory Attributes

The criteria for selection of sensory attributes are that they can discriminate between the samples, are relevant to the specific seafood, they must be nonredundant, and be cognitively clear to the assessors.

In the previous chapter, there is a long list of attributes used in the literature.

17.4 Examples of Sensory Characterization of Seafood

Green-Petersen et al. [23] gave an overview of both the sensory properties and differences between the most common salmonids products available on the Danish market. Twelve salmon samples, which differed in storage condition, packaging, and species were used in the experiment. All the

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

samples were obtained from local shops or companies and bought as consumer products. There were nine samples of *S. salar*, two were modified atmosphere packed (MAP), four were stored in ice, and three were frozen. There were also two frozen samples of *Oncohynchus kisutch* and one frozen sample of *Oncorhynchus keta*. The four samples stored in ice had very similar sensory profile described by the attributes sea/seaweed odor, the flavors fresh fish oil, sweet and mushroom, and the texture juicy and oily. Even though the ice storage samples represented different fish farms, different batches, and different storage times in ice (7 or 16 days), they did not observe any clear sensory differences which were in agreement with Sveinsdóttir et al. [20]. The MAP samples stored for 5 days and the ice storage samples had a relatively similar sensory profile. Whereas the MAP packed that was stored for 7 days was rather different, it was rancid and sour. For the frozen samples, the results show that a longer freezing time gave a more soft texture, an increase in discolor and a decrease in sea/seaweed odor. However, they found that freezing only had little influence on flavor. The results indicate that in general, the sensory properties of *O. keta* and *S. salar* are fairly similar. Furthermore, the results indicate that the sensory properties of *O. kisutch* are very different from the sensory properties of *O. keta* and *S. salar*. The two samples of *O. kisutch* had a high intensity of firm texture, rancid flavor, and were discolored, combined with a low intensity of juicy and oily texture, sea/seaweed odor and the flavors sweet, fresh fish oil, and mushroom.

The length of starvation before slaughtering can have considerable influence on the sensory attributes. In farmed Atlantic salmon (*S. salar*), fresh flavor was significantly reduced in groups starved from 30 to 86 days, whereas no significant differences were found among groups starved for 0–30 days. The sensory test was performed on day 13–16 postmortem fish [35].

The content of the feed can influence not only the growth rate, but also the sensory characteristics of the fish. For Atlantic halibut (*H. hippoglossus*) fed with a diet containing 20% or 39% fat, the sensory test showed that larger fish (2.1–2.7 kg) were characterized by a fresher and more acidic flavor and a more juicy consistency, compared to smaller fish (1.4 kg). The growth of the 20 halibut used in the sensory test showed that high growth was associated with small fish, which achieved higher scores for off-flavor and rancid flavor than the larger halibut with lower growth rate. This does not imply that a high growth rate is a contributing factor to the off-flavor or the rancid flavor of the small fish, but shows that these characteristics are typical for the small fish [3]. The odor for turbot (*Psetta maxima*) fed with three experimental diets (with 9% (w/w) added lipid–fish oil, soybean oil, or linseed oil) were described as having a fatty fish note, even though the lipid content of turbot muscle was very low. Grass and hay notes were also found to characterize the odor of flesh [43].

There can be large variation in the sensory characteristic of different fish species, but also similarities. Cardello et al. [39] characterized 17 fish species by sensory profiling and by using cluster analyzing of the data they found that the 17 species could be grouped in three major groups. The first group is characterized by primarily low fat, low flavor intensity, white-fleshed fish, and consists of tilefish (*Lopholatilus chamaeleonticeps*), pollock (*P. virens*), haddock (*Malanogrammus aeglefinus*), wolfish (*Anarhichas lups*), Atlantic cod (*G. morhua*), cusk (*Brosme brosme*), white hake (*Urophycis tenuis*), whiting (*Merluccius bilinearis*), blackback flounder (*Pseudopleuronectes americanus*), Atlantic halibut (*H. hippoglossus*), monkfish (*Lophius americanus*), and grouper (*Mycteroperca microlepis*). The second major group consists of the high fat, high flavor intensity, dark-fleshed fish, including bluefish (*Pomotomus saltatrix*), Atlantic mackerel (*Scomber scombrus*), weakfish (*Cynoscion regalis*), and striped bass (*Morone saxatilis*). The third group consists solely of swordfish (*Xiphias gladius*), but none of the sensory parameters described the swordfish very good. The swordfish was included in another study by Ref. [34]. In this study different saltwater fish, migratory coastal fish, coastal bottom fish, pelagic fish, deep-sea fish, freshwater fish, anadromous fish,

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and brackish water fish, in total 16 species was sensory characterized. By multivariate data analysis, four groups were observed in a biplot using PCA (principal component analysis). Red sea bream snapper (*Pagrus major*), common Japanese conger (*Conger myiaster*), Japanese eel (*Anguilla japonica*), and freshwater species, i.e., loach (*Misgurmus anguillicaudatus*), pond smelt (*Hypomesus nipponensis*), and carp (*Cyprinus carpio*) were grouped around the flavor "green." Migratory coastal fish species, i.e., sardine (*Sardinops melanosticta*), banded blue-sprat (*Spratelloides gracilis*), and chub mackerel (*Scomber japonicus*), were located close to "fish oil," "grilled fish," "sea breeze," and "fishy." Swordfish (*Xiphas gladius*), sablefish (*Anoplopoma fimbria*), and chum salmon (*O. keta*) were located close to "fried chicken." Slime flounder (*Microstmus achne*), pacific cod (*Gadus macrocephalus*), blue-fin tune (*Thunnus thynnus*), and yellowfin goby (*Acanthogobius flavimanus*) were grouped around "cooked fish," "sweet," "canned tuna," and "roasted soy sauce."

During ice storage of fish the intensity of the sensory attributes will change. Sensory profiling of ice stored farmed salmon showed that sensory attributes characterizing the salmon (*S. salar*) on day 1 were seaweed, cucumber, and sourish odor; sweetish, sourish, fish oil; and mushroom flavor and after 22–24 days of storage the salmon were characterized by rancid, sour, amine odor, and rancid flavor. The sensory attributes used in another storage experiment with farmed salmon stored in ice were grouped into "positive sensory parameters" and "negative sensory parameters." The samples from every second storage day were analyzed. The changes in the sensory attributes indicate that the salmon was approaching the end of acceptable flavor after 20–21 days, when the salmon was characterized by increasing the intensity of sour, amine, and rancid odor and flavor. All positive attributes had a high intensity and were very characteristic for the salmon at the beginning of the storage time, but after 21–22 days of storage they were hardly detectable. It was concluded from the result of the sensory profiling that the shelf life for salmon, where the fish is no longer fit for human consumption, was 20 days in ice [20].

In storage studies with MAP, the development of sensory attributes are different than for ice storage of the same fish species. Hong et al. [17] found that the odor of Atlantic mackerel (*S. scombrus* L.) during MAP storage changed from day 0 (seaweed, fishy, and rancid) to 7 days of storage (seaweed, cucumber-like, sour, fishy, painty, and rancid) and again from 14 days of storage (seaweed, sour, fishy, and rancid) to 21 days of storage (seaweed, sour, fishy, metallic, and rancid).

The rapid development of rancidity in stored muscle from fish such as mackerel, herring, capelin, and bluefish is often attributed to the high level of lipid that these species contain. However, studies by Richards and Hultin [29] indicate that blood-mediated oxidation of washed cod (*G. morhua*) lipids required ≤0.1% phospholipid to cause rancidity. They also found with long-term, frozen storage of mackerel (*S. scombrus*) muscle, sensory quality deterioration occurred in spite of no measurable change in fatty acid composition.

Manipulation of the environmental salinity affected the flavor of frozen white shrimp (*Penaeus vannamei*). Since free amino acids are major osmo-effectors in shrimp and also primary flavor producers in marine products, more flavorful shrimp can be produced by acclimation to high environmental salinities [16].

Bak et al. [44] investigated the effect of packaging atmosphere, temperature fluctuation, and light exposure on frost formation, lipid oxidation, discoloration, and meat toughness of shell-on-cold-water shrimps (*Pandalus borealis*) during 12 months of frozen storage. They found that the single most important handling factor affecting shrimp quality was the exposure to oxygen during storage. Rancid flavor was significantly higher for the samples packed in atmospheric air compared to the samples packed in modified air. The effect of light on the rancid flavor of atmospheric air-packed shrimps was significant. The sensory score for rancid

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

flavor for modified air-packed samples did not increase significantly between 9 and 12 months of frozen storage.

The sensory evaluation of shrimp meat toughness revealed a clear effect of the packaging method and storage conditions. They found a significantly higher score for toughness for the samples packed in atmospheric air compared to the samples packed in modified air. In addition, storage in light resulted in significantly tougher shrimp meat. The sensory score for toughness was almost constant for the samples packed in modified air for the first 9 months of storage, whereas a significant increase was observed between 9 and 12 months of storage.

Erikson et al. [45] investigated different frozen shrimp, which was obtained from commercial distributors. The samples were identified as Gulf brown shrimp (*Penaeus aztecus*), Gulf white shrimp (*Penaeus setiferus*), Gulf pink shrimp (*Penaeus duorarum*), Georgia brown shrimp (*P. aztecus*), Georgia white shrimp (*P. setiferus*), Burma black tiger shrimp (*P. monodon*), Belise white shrimp (*P. vannamei* or *Penaeus stylirostris*), Colombia white shrimp (*P. vannamei* or *P. stylirostris*), Honduras white shrimp (*P. vannamei* or *P. stylirostris*), and Mexican white shrimp (*P. vannamei* or *P. stylirostris*). Sensory attributes that distinguish the frozen shrimp was associated with appearance. In the case of Burma black tiger shrimp, distinguishing features were shell darkness and stripe darkness of the raw products and red/orange color of the cooked meat product. Belise white shrimp, were found to have a muted shell color and significantly lower shell and stripe darkness than the other shrimp samples. While the high intensity of brown meat color differentiated the Colombia white shrimp from other shrimp, Georgia white shrimps were unique from the other samples in the high iridescence displayed in the tail of the raw product. Erikson et al. [45] found that iridescence of Georgia white shrimp was nearly twice as much than the other shrimp samples including Gulf white shrimp (the same species of shrimp, but harvested from a different location). Commercial claims stated that Georgian white shrimps are sweet, but Erikson et al. [45] found the highest sweetness intensity in Burma black tiger shrimp. Georgia white shrimps were characterized as having the highest cooked shrimp flavor, but the intensity was not significantly different from Gulf brown, Georgia brown, Gulf pink, or Mexican white shrimp.

Erikson et al. [45] also found that notable differences in aroma or basic taste attributes occurred, which could be ascribed to variations in processing applied to the commercially available shrimp samples. For example, old shrimp aroma in the raw product was significantly higher in Mexican white shrimp than other shrimp samples. At the same time, blotchiness ratings were also significantly higher in Mexican white raw and cooked shrimps and they concluded that the shrimp could have been held for some period of time prior to freezing. Another variation in processing that was also perceived by the trained panel was the addition of the additives, sodium tripolyphosphate and sodium bisulfite, in Gulf shrimp. In fact salty intensity in Gulf pink shrimps were nearly twice than those of other shrimp while their sweetness scores were 20% lower than other shrimp.

In the investigation, the trained panel found significant differences between fresh and commercially available frozen shrimp (Georgia white shrimp (*P. setiferus*) and Gulf pink shrimp (*P. duorarum*)) for 18 of the 30 sensory attributes. In terms of appearance, fresh shrimps were glossier than frozen shrimp for both the raw and cooked products. The most notable change in appearance for the raw product, however, was a loss in tail iridescence. While for cooked products the most notable changes in appearance were loss of red/orange color on the shrimp surface. Frozen shrimp had a higher intensity of cooked shrimp flavor, cooked shrimp aroma, and ocean/seawater aroma than fresh shrimp whereas no difference in the old shrimp aroma was found. They also found changes in texture, shrimp that had been frozen were firmer and less juicy than fresh shrimp. Because the frozen shrimp were commercially obtained in this study, the period of time they had been in frozen storage is unknown.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

References

1. Reinitz GL, Orme LE, and Hitzel FN. 1979. Variations of body composition and growth among strains of rainbow trout (*Slamo gairdneri*). *Transactions of the American Fisheries Society* 108:204–207.
2. Einen O and Skrede G. 1998. Quality characteristics in raw and smoked fillets of Atlantic salmon, *Salmo salar*, fed high-energy diets. *Aquaculture Nutrition* 4:99–108.
3. Nortvedt R and Tuene S. 1998. Body composition and sensory assessment of three weight groups of Atlantic halibut (*Hippoglossus hippoglossus*) fed three pellet sizes and three dietary fat levels. *Aquaculture* 161:295–313.
4. Nielsen D, Hyldig G, Nielsen HH, and Nielsen J. 2005b. Lipid content in herring (*Clupea harengus* L.)—Influence of biological factors and comparison of different methods of analyses: Solvent extraction, Fatmeter, NIR and NMR. *Lebensmittel-Wissenschaft und-Technologie* 38:537–548.
5. Ando S, Hatano M, and Zama K. 1985. Deterioration of chum salmon (*Oncorhynchus keta*) muscle during spawning migration—1. Changes in proximate composition of chum salmon muscle during spawning migration. *Comparative Physiology and Biochemistry* 80B:303–307.
6. Ando S and Hatano M. 1986. Biochemical characteristics of chum salmon muscle during spawning migration. *Bulletin of the Japanese Society of Fisheries* 52:1229–1235.
7. Borresen T. 1992. Quality aspects of wild and reared fish. In Huss HH, Jacobsen M, and Liston J (eds.), *Quality Assurance in the Fish Industry*; *Proceedings of an International Conference*, Copenhagen, Denmark August 1991. Elsevier, Amsterdam, the Netherlands, pp. 1–17.
8. Buttkus HJ. 1963. Red and white muscle of fish in relation to rigor mortis. *Journal of the Fisheries Board of Canada* 20:45–58.
9. ISO 8586-1. 1993. *Sensory Analysis—General Guidance for the Selection, Training and Monitoring of Assessors—Part 1: Selected Assessors*. International Organization for Standardization, Switzerland.
10. ISO 8589. 1988. *Sensory Analysis—General Guidance for the Design of Test Rooms*. Reference number ISO 8589:1988(E).
11. ISO 11035. 1994. *Sensory Analysis—Identification and Selection of Descriptors for Establishing a Sensory Profile by a Multidimensional Approach*. International Organization for Standardization, Switzerland.
12. Nielsen D, Hyldig G, and Sørensen R. 2005c. An effective way to minimize drifting and monitor the performance of a sensory panel during long-term projects—A case study from a project on herring quality. *Journal of Sensory Studies* 20:35–47.
13. Bjerkeng B, Refstie S, Fjalestad KT, Storebakken T, Røbotten M, and Roem AJ. 1997. Quality parameters of the flesh of Atlantic salmon (*Salmo salar*) as affected by dietary fat content and full-fat soybean meal as a partial substitute for fish meal in the diet. *Aquaculture* 157:297–309.
14. NMKL Procedure NR. 6. 1998. Generelle retningslinier for kvalitetssikring af sensoriske laboratorier. Nordisk Metodikkomité for Levnedsmidler. http://www.nmkl.org/Engelsk/index.htm
15. Meilgaard M, Civille GV, and Carr BT. 2006. *Sensory Evaluation Techniques*, 4th ed., CRC Press, Boca Raton, FL.
16. Papadopoulos LS and Finne G. 1986. Effect of environmental salinity on sensory characteristics of penaeid shrimp. *Journal of Food Science* 51:812–814.
17. Hong LC, Leblanc EL, Hawrysh ZJ, and Hardin RT. 1996. Quality of Atlantic mackerel (*Scomber scombrus* L.) fillets during modified atmosphere storage. *Journal of Food Science* 61:646–651.
18. Warm K, Nielsen J, and Hyldig G. 2000. Sensory quality criteria for five fish species. *Journal of Food Quality* 23:583–601.
19. Bøkness N, Jensen KN, Guldager HS, Østerberg C, Nielsen J, and Dalgaard P. 2002. Thawed chilled Barents Sea cod fillets in modified atmosphere packaging-appæication of multivariate data analysis to select key parameters in good manufacturing practice. *Lebensmittel-Wissenschaft und-Technologie* 35:436–443.
20. Sveinsdóttir K, Hyldig G, Martinsdóttir E, Jørgensen B, and Kristbergsson K. 2003. Development of quality index method (QIM) scheme for farmed Atlantic salmon (*Salmo salar*). *Food Quality and Preferences* 14:237–245.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

21. Nielsen D, Hyldig G, Nielsen HH, and Nielsen J. 2004. Sensory properties of marinated herring (*Clupea harengus*)—Influence of fishing ground and season. *Journal of Aquatic Food Product Technology* 13:3–24.
22. Nielsen D, Hyldig G, Nielsen J, and Nielsen HH. 2005a. Sensory properties of marinated herring (*Clupea harengus*) processed from raw material from commercial landings. *Journal of the Science of Food and Agriculture* 85(1):127–134.
23. Green-Petersen DMB, Nielsen J, and Hyldig G. 2006. Sensory profiling of the most common salmon products on the Danish market. *Journal of Sensory Studies* 21:415–427.
24. Schubring R and Oehlenschläger J. 1997. Comparison of the ripening process in salted Baltic and North Sea herring as measured by instrumental and sensory methods. Zournal von Lebensmittel Untersuchung Forschung A 205:89–92.
25. Rasmussen RS, Ostenfeld TH, Rønsholdt B, and McLean E. 2000. Manipulation of end-product quality of rainbow trout with finishing diets. *Aquaculture Nutrition* 6:17–23.
26. Ginés R, Valdimarsdottir T, Sveinsdottir K, and Thorarensen H. 2004. Effect of rearing temperature and strain on sensory characteristics, texture, colour and fat of Arctic charr (*Salvelinus alpinus*). *Food Quality and Preferences* 15:177–185.
27. Stohr V, Joffraud JJ, Cardinal M, and Leroi F. 2001. Spoilage potential and sensory profile associated with bacteria isolated from cold-smoked salmon. *Food Research International* 34:797–806.
28. Morita K, Kubota K, and Aishima T. 2001. Sensory characteristics and volatile components in aroma of boiled prawns prepared according to experimental designs. *Food Research International* 34:473–481.
29. Richards M and Hultin HO. 2001. Rancidity development in a fish model system as affected by phospholipids. *Journal of Food Lipids* 8:215–230.
30. Cardinal M, Gunnlaugsdottir H, Bjoernevik M, Ouisse A, Vallet JL, and Leroi F. 2004. Sensory characteristic of cold-smoked Atlantic salmon (*Salmo salar*) from European market and relationships with chemical, physical and microbiological measurements. *Food Research International* 37:181–193.
31. Whitfield FB, Helidoniotis F, Shaw KJ, and Svoronos D. 1997. Distribution of bromophenols in Australian wild-harvested and cultivated prawns (Shrimp). *Journal of Agriculture and Food Chemistry* 45:4398–4405.
32. Rørå AMB, Kvåle A, Mørkøre T, Rørvik KA, Stein SS, and Thomassen MS. 1998. Process yield, colour and sensory quality of smoked Atlantic salmon (*Salmo salar*) in relation to raw material characteristics. *Food Research International* 31:601–609.
33. Whitfield FB, Helidoniotis F, and Smith D. 2002. Role of feed ingredients in the bromophenol content of cultured prawns. *Food Chemistry* 79:355–365.
34. Morita K, Kubota K, and Aishima T. 2003. Comparison of aroma characteristics of 16 fish species by sensory evaluation and gas chromatographic analysis. *Journal of the Science of Food and Agriculture* 83:289–297.
35. Einen O and Thomassen MS. 1998. Starvation prior to slaughter in Atlantic salmon (*Salmo salar*) II. White muscle composition and evaluation of freshness, texture and colour characteristics in raw and cooked fillets. *Aquaculture* 169:37–53.
36. Johansson L, Kiessling A, Kiessling K-H, and Berglund L. 2000. Effects of altered ration levels on sensory characteristics, lipid content and fatty acid composition of rainbow trout (*oncorhynchus mykiss*). *Food Quality and Preference* 11:247–254.
37. Edmunds WJ and Lillard DA. 1979. Sensory characteristics of oysters, clams and cultured and wild shrimp. *Journal of Food Science* 44:368–373.
38. Farmer LJ, McConnell JM, and Kilpatrick DJ. 2000. Sensory characteristic of farmed and wild Atlantic salmon. *Aquaculture* 187:105–125.
39. Cardello AV, Sawyer MF, Prell P, Maller O, and Kapsalis J. 1983. Sensory methodology for the classification of fish according to "Edibility Characteristics". *Lebensmittel-Wissenschaft und-Technologie* 16:190–194.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

40. Bett KL, Ingram DA, Grimm CC, Vinyard BT, Boyette KDC, and Dionigi CP. 2000. Alteration of the sensory perception of the muddy/earthy odorant 2-methylisoborneol in channel catfish *Ictalurus punctatus* fillet tissues by addition of seasonings. *Journal of Sensory Studies* 15:459–472.
41. Sivertsvik M, Rosnes JT, Vorre A, Randell K, Ahvenainen R, and Bergslien H. 1999. Quality of whole gutted salmon in various bulk packages. *Journal of Food Quality* 22:387–402.
42. Hemre G-I, Karlsen Ø, Eckhoff K, Tveit K, Mangor-Jensen A, and Rosenlund G. 2004. Effect of season, light and diet on muscle composition and selected quality parameters in farmed Atlantic cod, *Gadus morhua* L. *Aquaculture Research* 35:683–697.
43. Sérot T, Regot C, Prost C, Robin J, and Arzel J. 2001. Effect of dietary lipid sources on odour-active compounds in muscle of turbot (*Psetta maxima*). *Journal of the Science of Food and Agriculture* 81:1339–1346.
44. Bak LS, Andersen AB, Andersen EM, and Bertelsen G. 1999. Effect of modified atmosphere packaging on oxidative changes in frozen stored cold water shrimp (*Pandalus borealis*). *Food Chemistry* 64:169–175.
45. Erikson MC, Bulgarelli MA, Resurreccion AVA, Vendetti RA, and Gates KA. 2007. Sensory differentiation of shrimp using a trained descriptive analysis panel. *Food Science and Technology* 40:1774–1783.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

MILK AND DAIRY FOODS

IV

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 18

Color

Laurent Dufossé and Patrick Galaup

Contents

18.1 Introduction 320
18.2 Description of the Techniques in Use in Dairy Food Color Analysis 321
18.2.1 Color Determination Using Traditional Laboratory Visible Spectrophotometers 321
18.2.2 Visible and Near-Infrared Reflectance (VNIR) Spectrophotometry 321
18.2.3 Tristimulus Colorimetry 322
18.2.4 Spectrophotometers Dedicated to Color Analysis 322
18.2.5 Color Chart or Color Fan 323
18.2.6 Computer Vision, Digital Scanning, and Image Analysis 324
18.2.7 High-Performance Liquid Chromatography (HPLC) of Pigments 324
18.3 Practical Applications in Dairy Foods Analysis 324
18.3.1 Anteprocessing (i.e., Milk Production Related to Cattle/Cow Feeding) 324
18.3.2 Processing 326
18.3.2.1 Butter 326
18.3.2.2 Cheese-Making Process 327
18.3.2.3 Use of Technologies Such as High-Pressure Processing or Ultrafiltration 327
18.3.2.4 Modification of Dairy Food Composition (Substitution of Milk Powder by Whey Powder or Soy Proteins, Use of Fat Replacers, Addition of Chitosan or Orange' Fibers…) 328
18.3.2.5 Studies about the Whiteness of Mozzarella or Browning of the Same Cheese When Used in Pizza 329

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

18.3.2.6 Role of the Microflora in the Development of Color at the Surface of Soft Cheeses 329
18.4 Postprocessing 331
18.5 Quality Control 332
18.6 Conclusion 334
References 336

18.1 Introduction

Even when we just look around, a wide variety of colors leap into our eyes. We are surrounded by an infinite variety of colors in our daily lives. An average person can distinguish as many as 350,000 different colors, among which are 5,000 distinguishable white colors, but the number of basic color terms is confined to not more than 11 basic expressions, regardless of cultures or languages [1]. However, unlike length or weight, there is no physical scale for measuring color, making it unlikely that everyone will answer in the same way when asked what a certain color is. For example, if we say "yellow butter" or "yellow cheddar" to people, each individual will imagine different yellow colors, because their color sensitivity and past experiences will be different. This is the problem with color [2].

Color is an important component of quality throughout the agricultural and food industries. Because color is closely associated with factors such as freshness, ripeness, desirability, and food safety, it is often a primary consideration for consumers when making purchasing decisions. For such reasons, color is an important grading factor of most food products. Color is also a criterium that could be monitored during production of milk related to animal feeding, processing of dairy products, or monitoring of such products during the shelf life.

Consumers rely primarily upon their vision to evaluate product color. Because color perception differs from person to person, and depends upon lighting and numerous other factors, many industries rely on human vision coupled with an instrumental system of color measurement. These instruments attempt to simulate the manner in which the average human eye sees the color of an object, under specified illumination conditions, and provide a quantitative measurement. The reflected spectral data are transformed or filtered to provide reproducible color values in accordance with the standards developed by the Commission Internationale de l'Éclairage (CIE). In the agricultural and food industries the most popular numerical color-space system is the $L^*a^*b^*$, which is also referred to as the CIELAB system, originally defined by the CIE in 1976 [3] (L^* indicates lightness and a^* and b^* are the chromaticity coordinates).

Hue, lightness, saturation, the world of color is a mixture of these attributes. Hue: butter is yellow, cheddar is orange, *Penicillium*-veined cheese is partly blue-green … that is how we think of color in every day language. Hue is the term used in the world of color for the classifications of red, yellow, blue… The continuum of these hues results in a color wheel. Lightness: colors can be separated into bright and dark colors when their lightnesses (how bright they are) are compared. This lightness can be measured independently of hue. Saturation: vivid colors, dull colors, this attribute is completely separate from those of both hue and lightness.

The first part of this chapter presents a description of the techniques in use in dairy food color analysis. Then practical applications of color measurements are presented in anteprocessing (i.e., color of milk related to cattle feeding), processing (e.g., butter, cheese), postprocessing, and quality control of dairy food products.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

18.2 Description of the Techniques in Use in Dairy Food Color Analysis

An object absorbs part of the light from the light source and reflects the remaining light. This reflected light enters the human eye, and the resulting stimulation of the retina is recognized as the object's "color" by the brain. Each object absorbs and reflects light from different portions of the spectrum and in different amounts; these differences in absorbance and reflectance are what make the colors of different objects different.

18.2.1 Color Determination Using Traditional Laboratory Visible Spectrophotometers

When a material is illuminated by light, specific wavelengths are absorbed depending on the molecular structure present. This is caused by electrons in the ground-state molecule absorbing light energy and moving to an excited state. The absorption intensity depends on the wavelength and the absorption spectrum (curve measuring absorption intensity changes accompanying wavelength changes for monochromatic light illuminating a material) is characteristic of a specific material.

Restricted to liquids, the color measurements are usually made on a UV–vis diode array spectrophotometer by using quartz cuvettes (width of cuvettes is subject to variation to prevent the apparatus from saturating). The entire visible spectra (380–770 nm) at 2 nm intervals are measured and recorded after zeroing the apparatus. The selection of the blank reference, which is of paramount importance to achieve a meaningful color specification, should be made very carefully. Absorbance values are then related to 10 nm bandwidths and subsequently referred to into transmittance. In conformity with the weighed-ordinate method, the transmittances of the samples along the spectrum are weighed considering the features of the visual reference conditions chosen: Standard Illuminant D65 (related to a color temperature of 6504 K) and CIE 1964 Standard Observer (vision angle of 10°) to obtain the tristimulus values. Furthermore, the color parameters more related to the psychophysical characteristics of color, which correspond to the angular coordinates of $L^*a^*b^*$ (CIELAB) color space, i.e., lightness (L^*), chroma (C^*ab), and hue (hab), are also calculated and taken into account. The calculations necessary to obtain all the relevant color parameters could be performed by means of softwares such as CromaLab© [4].

18.2.2 Visible and Near-Infrared Reflectance (VNIR) Spectrophotometry

Near-infrared reflectance (NIR) spectrophotometers are widely used throughout the food and agricultural industries [5] to measure chemical constituents such as protein, oil, starch, fiber, and moisture. NIR has been used to assess chemical quality of food products for which color is important. Approximately 20 years ago, NIR instruments became available with extended spectral range which included the visible region (VNIR instruments). The visible region allowed for the measurement of pigments such as carotenoids by measuring absorbances (reflectances) at specific wavelengths associated with the pigments. Although these analyses quantified the pigments that contributed to the color of the product, they did not provide the actual color of the product being examined. The feasibility of using a VNIR instrument to measure color, in accordance with the principles of the CIE, was then demonstrated, in comparison to the color values obtained from a colorimeter specifically designed to provide

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

color-space values. The VNIR instruments have excellent potential to provide color information to complement the biochemical information normally provided by the NIR region. To facilitate this in an efficient manner, the calculations should be incorporated as part of a standard software package, which would eliminate the tedious requirement to export the spectral data for each sample to a supplemental spreadsheet. The software should also provide a means of calibrating the color data to a set of standards. This calibration process for color would be quite distinct from the calibration normally associated with NIR work. The color calibration would primarily involve correcting the calculated $L^*a^*b^*$ values for slight differences in optics and geometry among instruments, and would only need to be done occasionally with a set of color standards fitted to the appropriate sample cells. The software should also include the ability to provide $L^*a^*b^*$ values based on different illuminants, and facilitate conversions to other color-space systems. Using VNIR instruments in this manner provides an efficient means of simultaneously providing chemical and color quality information about dairy products [6].

18.2.3 Tristimulus Colorimetry

Although the human eye cannot quantify colors accurately, with a colorimeter it is simple. As seen previously, unlike the subjective expressions commonly used by people to describe colors verbally, colorimeters express colors numerically according to international standards. By expressing colors in this way, it makes it possible for anyone to understand what color is being expressed. Further, a person's perception of a single color may change depending on the background or on the light source illuminating the color. Colorimeters have sensitivities corresponding to those of the human eye, but because they always take measurements using the same light source and illumination method, the measurement conditions will be the same, regardless of whether it is day or night, indoors or outdoors. This makes accurate measurements simple [7]. The colorimeter is mainly used in production and inspection applications for the color difference measurements. Minute color differences can be expressed numerically and easily understood. In the $L^*a^*b^*$ color space, color difference can be expressed as a single numerical value, ΔE^*ab, which indicates the size of the color difference but not in what way the colors are different.

A tristimulus colorimeter is a combination of a sensor and a microcomputer. The "sensor" is a set of three filtered sensors to have nearly the same color sensitivity as the human eye [8]. They receive light from the object and transmit information to the microcomputer. The latter then determines numerical values that are delivered to the user.

A related problem is if, for example, the colors of two objects appeared to be the same under daylight but appeared to be different under indoor room lighting. Such a phenomenon, in which two colors appear the same under one light source but different under another, is called metamerism. For metameric objects, the spectral reflectance characteristics of the colors of the two objects are different, but the resulting tristimulus values are the same under one light source and different from each other under another. Tristimulus colorimeters can generally take measurements under only Standard Illuminant C and Standard Illuminant D65, both of which represent daylight and which have very similar spectral power distributions; because of this, tristimulus colorimeters cannot be used to measure metamerism.

18.2.4 Spectrophotometers Dedicated to Color Analysis

In addition to displaying numerical color data, a spectrophotometer can also display a graph of the color's spectral reflectance (colors are created by mixing various wavelengths of light in appropriate

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

proportions). A spectrophotometer measures the light reflected from the object at each wavelength or in each wavelength range (up to 40 sensors); this data can then be displayed on a graph to provide more detailed information about the nature of the color. This device is used for high-precision analysis and accurate color management mainly in laboratories, and research and development applications. The spectrophotometer, on the other hand, is equipped with the spectral power distributions of a wide range of illuminants and thus can determine metamerism. Moreover, with the spectrophotometer's capability to display spectral reflectance graphs, you can see exactly how the spectral reflectances of the two colors are different.

18.2.5 Color Chart or Color Fan

Color charts are well known in industries such as painting, home design, and car building but also in the food industry. For example these are used for determination of the color of egg yolk, salmon flesh… (Figure 18.1). The charts could be used alone in proprietary systems or could also

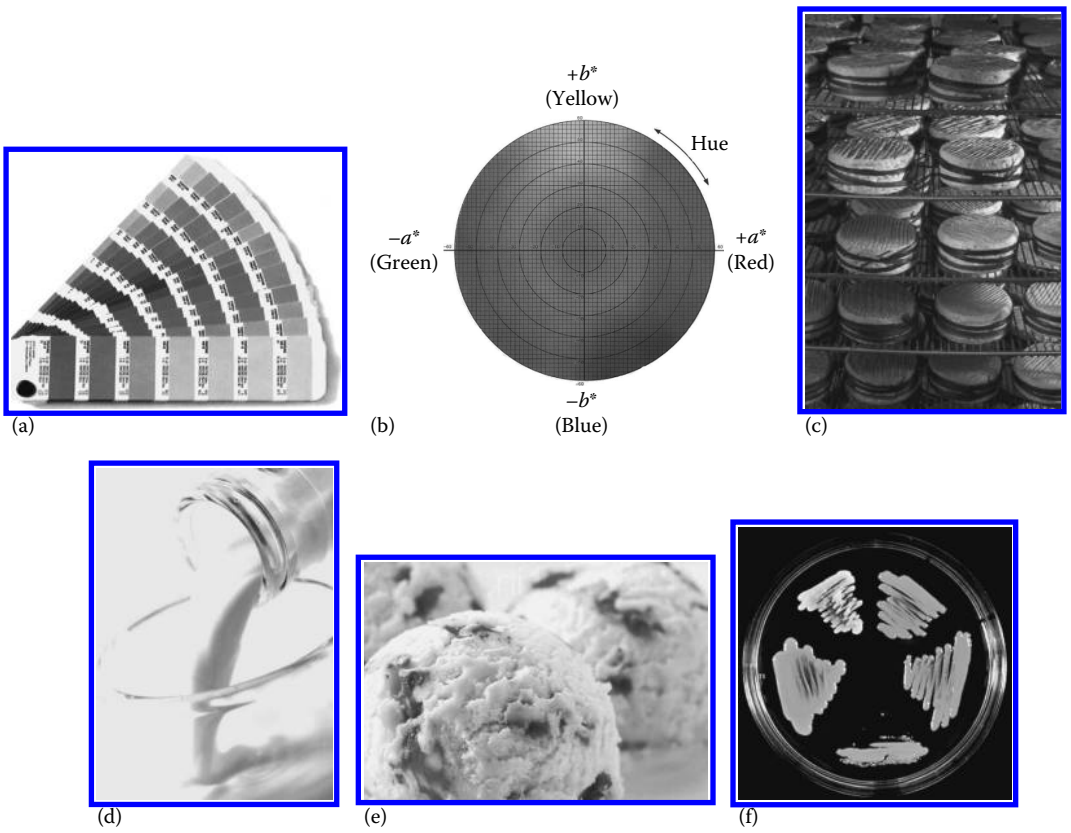


Figure 18.1 (a) Color fan; (b) CIE *L*a*b** color space; (c) Livarot cheeses on aging in a cellar; (d) milk, the color of which is due to light scattering or presence of pigments (e.g., carotenoids), (e) ice cream with added colorants; and (f) strains of *B. linens*, a bacteria used for surface ripening of soft cheeses. (From Anonymous, *Precise Color Communication. Color Control, from Perception to Instrumentation*, Konica-Minolta Sensing Inc., Japan, 1998. With permission.)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

be translated into $L^*a^*b^*$ values. The charts on paper are then used to individually score the food products without using an expensive electronic device. The main drawbacks are the nonstandardized light environment and the subjectivity of the human sensory judgement.

18.2.6 Computer Vision, Digital Scanning, and Image Analysis

Image analysis techniques using computer vision systems have been increasingly adopted for variety classification and quality evaluation of food materials and products. Wang and Sun [9] developed a computer vision method to evaluate the melting property of cheese. Researchers also used computer vision methods to analyze the color of pork, beer, and potato chips. A computer vision system includes a lens, a camera, a frame grabber, a monitor, a computer, and a software. The computer vision method provides noncontact measurement; therefore, there are no limitations on the temperature, size, and shape of samples. Compared with conventional methods using colorimeters, the computer vision method is efficient and provides more information on the color change of cheese by making continuous measurement possible. It also has the advantage of handling surfaces with uneven color distributions. Among the studies conducted is the influence of baking temperature and time on the browning property of cheese. Since Cheddar and Mozzarella cheeses are intensively used as toppings, the monitoring of the browning property of both cheeses is of high interest.

18.2.7 High-Performance Liquid Chromatography (HPLC) of Pigments

All the methods presented previously mostly deal with direct measurement of color, not with the identification of the compounds that are responsible for that color. To resolve mixtures of colorants, the usual alternatives are chromatographic techniques, such as liquid chromatography (LC) or thin-layer chromatography, and capillary electrophoresis. LC is often the preferred choice as it provides unrivaled resolution and lends itself readily to easy coupling with sensitive and selective detectors. LC using UV–visible, fluorescence, mass spectrometry, or diode-array detection (DAD) has been used to determine natural and synthetic colorants in dairy foods [10].

18.3 Practical Applications in Dairy Foods Analysis

18.3.1 Anteprocessing (i.e., Milk Production Related to Cattle/Cow Feeding)

The white appearance of milk results from its physical structure (i.e., the dispersion of both casein micelle and fat globules responsible for the diffusion of incident light and consequently of the high L^* value of milk). All the measurement conditions such as temperature and composition parameters such as fat, protein, Ca, and P, as well as technological treatments that influence the physical structure of milk also modify the L^* component of the milk color measurement. Milk color assessment is mainly applied to identify technological parameters such as homogenization, thermal treatment (including Maillard reactions), fat concentration, photodegradation, storage conditions, or additives. The "a^*" and "b^*" components of the milk color are also influenced by a number of factors linked to milk's natural pigment concentration. The main pigments are

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

riboflavin, a green compound present in the aqueous phase which is a strong photosensitizer, and β-carotene and to a lesser extent lutein which have maximal absorbance at wavelengths 497–466 and 481–453 nm, respectively. Milk carotenoids are responsible for the yellow coloration (higher "*b**" value) of cattle milks in comparison to sheep and goat milks which are devoid of β-carotene [11].

The components of milk color are linked to milk's natural pigment concentration from carotenoids, protein, and riboflavin. Several studies have looked at the impact of feed on milk color pigments. Cows fed grass silage produced milk with fat that was more yellow than that produced by cows fed hay. Other scientists found that concentrations of riboflavin, tocopherols, β-carotene, lutein, and zeaxanthine in milk were higher in cows fed grass silage than those fed maize silage. In another study, milk from cows fed grass silage produced milk with higher β-carotene than those fed hay and a switch from grass silage to hay diet induced a rapid decrease in the concentration of β-carotene. The development of a reflectance method considers all of components that contribute to color in one measurement and enables the measurement of milk as an opaque food, addressing the limitations of other methods. However, limitations of measuring milk color to predict carotenoid content with spectrocolorimetry were described [12].

Carotenoids are involved in the nutritional and sensory characteristics of dairy products, and are potential biomarkers for traceability of cows' feeding management. Nearly 10 carotenoids (i.e., xanthophylls and carotene) have been quantified in forages, and their concentrations vary highly according to the development stage and length of conservation. Sensitivity of β-carotene to ruminal degradation varies among studies, depending on its dietary source. Data suggest that carotenoid digestion would be linked to dietary lipids for transit, and to specific transporters of lipophilic molecules for absorption. Among ruminants, only bovines accumulate high concentrations of carotenoids, mainly β-carotene, possibly due to lower efficiency of vitamin A synthesis in enterocytes. Carotenoid flows in plasma and tissues in dairy cows remain to be investigated, especially the ability of adipose tissue to release β-carotene in depleted or underfed animals. Carotenoids in cows' milk mainly consist of all-*trans*-β-carotene and, to a lesser extent, lutein. In milk, concentration is more variable for β-carotene than for retinol, for which the plasma concentration is well regulated. Milk concentration of β-carotene depends on its dietary supply. Both animal and feeding factors that affect milk yield (i.e., breed, parity, physiological stage, level of intake) generally also control milk β-carotene concentration by concentration/dilution mechanisms, and by efficiency of extraction from plasma. The β-carotene concentration in cheese is highly linked to milk concentration, whereas high losses of retinol occur during cheese making. Feeding management of dairy cows allows efficient control of carotenoid concentration and color in dairy products [11]. Among the strangest supplementations of cow diet is the use of carrots [13] mixed with rapeseed to increase total carotene content (added value linked to color and biologically active compounds) together with unsaturated fatty acids (added value linked to spreadability and biologically active compounds). It was shown that the enrichment of carotene by feeding carrots counteracts the incorporation of unsaturated fatty acids.

Regarding the animal, the yellow coloration is higher in dairy products from cows than from ewes or goats (milk of goats and ewes, in contrast to that of cows, contains only retinol and xanthophylls and generally no β-carotene), and higher for cattle when breeds such as Jersey cows are used instead of Holstein or Montbéliarde.

The characteristics of the raw milk used play a major role, in particular in the case of products in which the modifications to the raw material during processing are restricted. The characteristics of raw milk used are dependent on factors linked to animal management (genetic, physiological, or dietary) that have increasingly been the focus of consumers' concern. These factors take special importance in the case of products with a protected designation of origin (PDO) or a protected geographical indication (PGI), which claims to have close links with milk production conditions.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

18.3.2 Processing

Research works are numerous in the field of dairy food processing and color. Normal processing of products such as butter, cheese [14], or yogurt has an impact on the final product color. Other points investigated that could have action on color are the followings: (i) use of technologies such as high-pressure processing or ultrafiltration, (ii) modification of dairy food composition (substitution of milk powder by whey powder or soy proteins, use of fat replacers, addition of chitosan or orange' fibers…), (iii) studies about the whiteness of mozzarella or browning of the same cheese when used in pizza, and (iv) role of the microflora in the development of color at the surface of soft cheeses.

As presented previously, carotenoids are important in dairy food color; however, these are sensitive to different physicochemical factors including air, oxidizing agents, and ultraviolet light. Their degradation is accelerated by increasing temperature and is catalyzed by mineral ions. Consequently, technological treatments such as heating and acidification applied when processing milk to produce dairy products, as well as the immediate processing and storage environment (i.e., light, temperature) are likely to degrade these micronutrients and influence the color and the vitamin potency of the resulting dairy products. Furthermore, processing of some milk products (e.g., cheese, butter) involves selective transfer of constituents from milk to milk products [11].

Milk carotenoids are transferred into butter and cheeses with minimal losses and thus contribute to their yellow coloration. Depending on the specific target market, the yellow color may be perceived as a positive or negative attribute. For instance, it is considered as negative for the color-sensitive markets of the Middle East. The marked yellow color of New Zealand milk fat resulting from the use of Jersey cows fed diets consisting predominantly of fresh grass raises problems for exportation. In contrast, in Europe, the yellow color of dairy products is generally seen as a positive trait that contributes to consumers' preference for dairy products produced in summer (e.g., derived from fresh grass-based diets). The hedonic preference of consumers for summer butter and cheese produced from pasture-fed cows is more marked when the sensory assessment is made under daylight in comparison to red light which masks the natural color differences.

The yellow coloration of dairy products is generally a more important issue in high-fat dairy products such as butter and full-fat cheeses. Because carotenoids are fat soluble, the yellow coloration is a function of both fat color and concentration, and fat color is a function of the carotenoid concentration in the fat.

18.3.2.1 Butter

Butter is a product that consists of roughly the same constituents as milk [15], but their distribution is different. In butter making, the fat content of the milk is concentrated approximately 20 times. The natural yellow color of butter is mainly due to carotene dissolved in the fat. Therefore, the natural butter color will vary with the carotene content in the feed of the dairy cattle [16]. Since lucerne, clover, and grass are rich in carotene, and beets, hay, and feed concentrates contain very little, the carotene content in butter will be highest in summer and autumn and lowest toward the end of winter and in early spring. It further depends on the ability of the cow to convert carotene into vitamin A, which strongly varies among breeds and individuals [17].

A butter color tone was developed by Meiji Dairies Corp., Tokyo, Japan and named as Japan Agriculture & Livestock Industries Corp. (ALIC) butter color tone. In Japan, the best quality

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

dairy products, including milk, cream, butter, and cheese, have an ALIC category 1 butter color tone (pale yellow). Butter is melted, centrifuged, and 2 g of butter fat is accurately weighed into a 10 mL volumetric flask and made to volume with hexane. The sample is then filtered and the absorbance measured at 455 nm converted per gram of fat [12].

18.3.2.2 Cheese-Making Process

During cheese manufacturing, between 800 and 950 g/kg of the carotenoids in the original milk are recovered in the curd. In many studies, little or no change in the concentration of these components has been observed during ripening or storage of cheese for up to a year. In a recent study [18], the rate of transfer of β-carotene and xanthophylls from milk fat to cheese fat, considering four cheese-making technologies and original milks covering a large range of concentrations of these micronutrients in milk fat was examined. On an average, 950 g/kg of β-carotene, but only 640 g/kg, of xanthophylls originally present in milk fat were recovered in cheese fat. In addition, despite the varying heating temperatures, acidification levels, and ripening times among the cheese-making technologies studied, the rate of carotenoid loss did not vary with the cheese-making technology. These results suggest that β-carotene is very stable, whereas xanthophylls are partially damaged and/or lost into whey during cheese making.

18.3.2.3 Use of Technologies Such as High-Pressure Processing or Ultrafiltration

Processing of food with high pressure rather than by traditional heating technologies offers unique advantages to consumers and the food industry. This technology can destroy microorganisms without causing significant changes to the sensory and nutritional attributes of the processed foods. Accordingly, it can produce some interesting effects and food products which are not possible with other preservation technologies. High-pressure or hyperbaric treatment of food is usually carried out in the range 300–1000 MPa at room temperature or a little higher; the pressure itself causes only a slight rise in the temperature of the food. Process times are short, usually between 2 and 30 min [19]. Milk treated at pressures of up to 500 MPa for a few minutes has been shown to have a shelf life of at least equivalent to HTST-pasteurized milk. When milk was subjected to high-pressure (250, 450, and 600 MPa) treatments for 30 min at 4°C, 20°C, and 40°C, a decrease in lightness (L^*) was observed for all, except for those at 250 MPa.

High-pressure homogenization (HPH) is a combined pasteurization/homogenization of raw milk. This process was assessed for reducing the size of fat globules and inactivation of microorganisms. Raw and commercially pasteurized and homogenized (CPH) milk samples were analyzed as controls. Small but significant differences in L^*-values were observed between raw, CPH, and HPH milk samples. For example, CPH milk was significantly whiter ($P < 0.05$) than raw milk, as expected; CPH and HPH samples had similar L^*-values. Differences in a^* and b^* values following treatments were very small. Overall, differences in instrumental color measurements between CPH and HPH milks were not visually obvious [20].

In another study, high-pressure processing was applied to fresh goats' milk cheeses (500 MPa for 5, 15, and 30 min at 10°C or 25°C). Color parameters hardly changed in the inner part of cheeses. Modifications on the surface were more pronounced. In 500 MPa/10°C cheeses, all parameters changed. Total color difference (ΔE^*) values of 500 MPa/10°C cheeses were higher than ΔE^* values of 500 MPa/25°C cheeses, mainly due to L^* value changes in samples treated at

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

10°C. The b^* value was the index that changed more with all treatments. It increased in pressure-treated cheeses, generally with increasing treatment times [21].

Protein, the most valuable component in milk, has increased in value over the past 20 years. Using ultrafiltration, fluid milks can be standardized to different protein percentages by separating skim milk into retentate and permeate fractions. These can then be combined and fat is added to produce milks with a 0%, 1%, 2%, or 3.3% fat and a range of true protein contents (usually lower protein contents compared to the starting milk). The target is to recover milk protein that could be sold as a food ingredient. Two studies [22,23] demonstrated that a modest protein standardization was feasible without noticeable color changes of the milks (a decrease in the protein content of 2% and 3.3% fat milks by ultrafiltration made them less white—lower L^* value).

18.3.2.4 Modification of Dairy Food Composition (Substitution of Milk Powder by Whey Powder or Soy Proteins, Use of Fat Replacers, Addition of Chitosan or Orange' Fibers…)

Milk whey is an important source of lactose, calcium, milk proteins, and soluble vitamins, which make this product to be considered as functional food and a source of valuable nutrients. Whey powder was used to substitute partially the milk powder in yogurt fortification. Five different formulations were obtained and analyzed for color (CIE $L^*a^*b^*$) after 1, 15, and 28 storage days at 5°C. Color was measured through surface reflectance of 55 mm high yogurt samples by using a spectrocolorimeter. In samples at 1 storage day, milk substitution implied a yellowing, with higher color purity and significant differences in brightness. The observed development was a decrease in color purity and an increase in yellowness after 15 days. Changes in color coordinates in line with milk substitution can be attributed to the different opacity level of gels, which increases with the casein proportion and their aggregation level. The greater the opacity the higher the sample brightness and the less pure the color [24].

A second example is the soy protein isolate (SPI) fortification of a low-fat dairy-based ice cream for the purpose of meeting any soy protein health claim labeling requirements. Low-fat ice cream mixes with 0% (control), 2%, and 4% (wt/wt) added SPI were made by substituting SPI for nonfat dried milk. Color differences among low-fat ice cream mixes with different levels of SPI were observed by instrumental analysis. The 4% SPI mix had a significantly lower L^* value than the control mix, indicating that ice cream mix fortified with SPI was less white in comparison to that of a typical low-fat ice cream. Values for a^*, which signify red (+) and green (–), were also significantly different among treatments. The a^* values for the low-fat ice cream mixes decreased with increasing SPI, demonstrating that the SPI mixes had more green color compared to the control. The b^* value, an indicator of blue (–) and yellow (+), was also different among treatments. The b^* value for the control increased with increasing levels of SPI, which demonstrates that the mixes increased from blue to yellow in color with increased SPI fortification [25]. Despite these data, low-fat dairy ice cream fortified with SPI may be a means of positively presenting soy protein to a broader market of consumers, among similar products, as they might appeal to a more traditional dairy consumer who could reject soy-based dairy analogs such as soymilk, soy yogurt, and soy ice cream.

Among additional studies, some focused on the effect of fat replacer on color of reduced fat mozzarella cheese [26] or ice cream [27], properties of low-fat Cheddar cheese manufactured with chitosan [28], or the impact of orange fiber addition on yogurt color during fermentation and cold storage [29].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

18.3.2.5 Studies about the Whiteness of Mozzarella or Browning of the Same Cheese When Used in Pizza

The ever increasing pizza popularity has led to the tremendous growth of cheese products, especially Cheddar and Mozzarella cheeses, which are the two major varieties of cheese used as toppings for pizza and some other prepared consumer foods. In order to achieve desirable quality of these consumer foods, the cheese products used are required to have certain functional properties such as melting, browning, oiling-off, shredability, and stretchability. Browning is a property of cheese that results in patches of darkened color on the cheese surface during baking before consumption. It is of high commercial interest to the manufacturers of both pizza and cheese because about 50% of pizza restaurants reported quality problems in cheese browning. It is widely believed that the browning of cheese during baking is mainly caused by Maillard reaction, which involves an interaction between reducing sugars and amino compounds. As a heat-induced process, the browning of cheese starts to occur during processing and slow cooking after processing. Attempts have been made to analyze the browning of cheese during baking to improve the quality of cheese used as toppings. Researchers have investigated the influence of different starter cultures on the residual sugar in cheese and thus on cheese browning. A strong correlation was found between the darkness of cheese color and galactose content for processed cheese and Mozzarella cheese. Though browning is considered as a defect in cheese whey [30] or processed cheese [31], for cheese used as toppings, browning may be considered as a desirable property. For the evaluation of cheese color, in addition to qualitative sensory evaluation, instrumental methods involving colorimeters/spectrophotometers, or image analysis techniques/computer vision are employed [9].

Mozzarella cheese undergoes significant change in temperature during baking on a pizza. A cheese temperature of 60°C–70°C is usually observed at the end of baking. After baking, the cheese begins to cool and is normally consumed at 40°C–50°C. Before measurements, the spectrophotometer is calibrated with a white reference tile. The L-value corresponds to whiteness, and higher L-values indicate whiter products (white = 100, black = 0). With products showing heterogeneous surface aspects (e.g., dark or brown patches), it is very important to increase the measurement area (cm^2). Manufacturers usually provide many measurement areas with increasing diameters. In one of the studies assessing this process [32], the L^*-value of Mozzarella increased dramatically during heating to 60°C and decreased during the subsequent cooling. The formation of a gel during heating increases light scattering, which increases L^*-value. During cooling, the gel dissociates and no longer scatters light, which decreases L^*-value. Similar results were obtained in Cheddar-like and Colby-like cheeses made with caprine milk [33] or processed cream cheese [34].

18.3.2.6 Role of the Microflora in the Development of Color at the Surface of Soft Cheeses

For the so-called smeared cheeses like Maroilles, Munster, Livarot, Epoisses, Limburger, Herve, Gubbeen, Taleggio, or Tilsit, a good aspect is mostly characterized by the occurrence of an orange-brown, sticky surface [35]. Since it is due to the development of cheese-ripening flora and to the interactions within this microflora (especially bacteria from the *Brevibacterium linens* group, *Arthrobacter* sp., *Microbacterium* sp., and coryneform bacteria), these typical dark yellow, orange, pink, or red-brick colors related to carotenoids such as isorenieratene and other pigments ensure that the cheese has developed aromas and melted texture. As knowledge of the representatives of the cheese-surface bacterial flora is quite limited, industrial manufacturers may sometimes encounter quality problems and the sole ripening pigmented microflora is not sufficient to give a

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

nice color. In this case, colorants such as annatto, paprika, or β-carotene are spread on the surface of the cheese during processing, as a means to produce standard and attractive products. Objective measurement of the smear color can be provided using a spectrocolorimeter ($L^*a^*b^*$ colorimetric system). The spectrocolorimetry can be used for the description of (i) the rind's color among various PDO cheeses (Figure 18.2), (ii) the relative heterogeneity observed for "on shelf cheeses" color in a specific PDO area, (iii) the assessment of color development on the surface of cheese versus time (quality control), and (iv) a screening technique for pigmented strains isolated from red-smear cheese rinds (biodiversity criteria) [36]. Concerning the latter item, up to now very few pigmented bacteria are available as commercial cultures for manufacturing of red-smear cheese. Traditionally, growth of the surface microflora is initiated with the help of mature cheeses, which release part of their microorganisms into the brine that is used to wash the young curds. Only about 15 different strains of *B. linens* group are present on the market with various orange hues [37]. Intensive use of these strains may contribute to a decrease in microbial diversity observed within the PDO cheeses, contributing to the loss of typicality for products proposed to the European consumers. Bacteria belonging to species other than *B. linens* group are also lacking in commercial offers made by microbial culture companies and this should be corrected as many authors emphasized their contribution in the ripening of smear cheese rind, e.g., *Microbacterium gubbeenense*, *Corynebacterium casei*, *Arthrobacter bergerei*, and *A. arilaitensis*. In order to be able to supply new pigmented strains to cheese producers, a screening experiment was conducted for 2 years [38] and 364 strains were isolated from Munster cheese (219 coryneform bacteria, 32 *Micrococcus*, 30 *Staphylococcus*, and 83 *B. linens*). Color coordinates were determined for each of them and the two dominant colors were orange and yellow (Figure 18.3 for a sample of 29 strains projected within the $L^*a^*b^*$ system). All

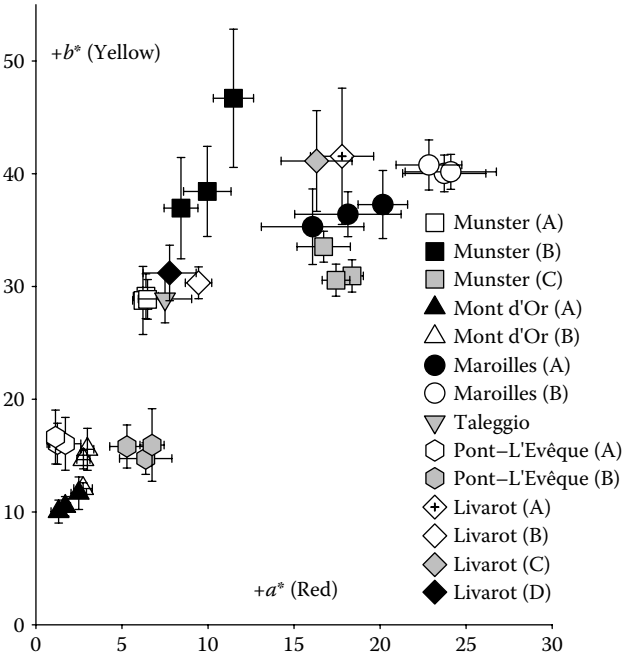


Figure 18.2 Color distribution among various PDO cheeses (10 measurements per cheese, letters A–D: cheese manufacturing plants, one distinct letter series within one PDO). (From Dufossé, L. et al., *Food Res. Int.*, 38, 919, 2005. With permission.)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

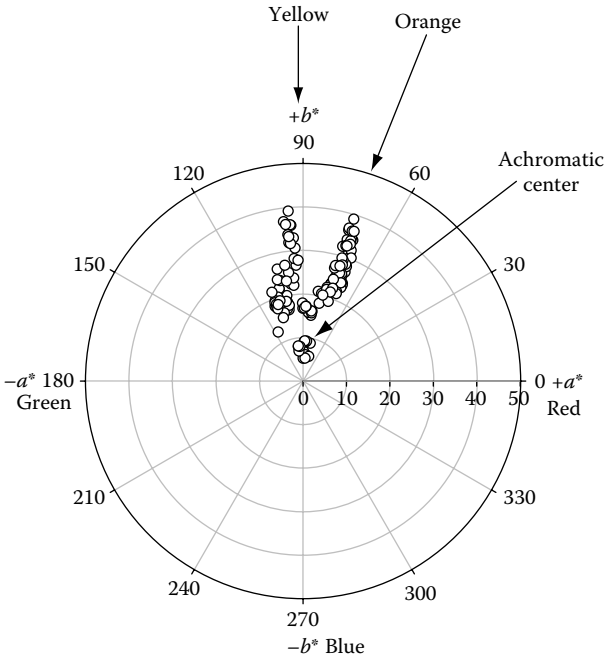


Figure 18.3 Position of 29 pigmented bacteria isolated from Munster cheeses in the CIE *L*a*b colorimetric system. (From Dufossé, L. et al., *Food Res. Int.*, 38, 919, 2005. With permission.)**

the orange strains were easily identified as strain members of the *B. linens* group (positive reaction with KOH, HPLC analysis of the pigments, 16S DNA sequencing). The technological important group of yellow pigmented coryneform flora of the smear cheese is quite homogeneous in colony morphology and physiological characteristics. Besides orange and yellow, a lot of strains were light colored (cream, beige) such as *Corynebacterium mooreparkense* sp. nov., five were pink but a total of 29 hues were described.

Other studies in the same field evaluated the influence of the yeast used for deacidification on the color of the bacterial biofilm [39–41]. For each bacterial biofilm, color was monitored by *L*C*h** (brightness, chroma, hue angle) spectrocolorimetry. Color intensity (function of chroma only) was higher when *Debaryomyces hansenii* was used, compared to deacidification with *Kluyveromyces marxianus*.

18.4 Postprocessing

Dairy foods are exposed to light from both natural and artificial sources throughout processing, packaging, and distribution, as well as at the retail level. Light-induced degradation of lipids, proteins, and vitamins in dairy foods causes both formation of off-flavors and color changes, which rapidly impair product quality and marketability and eventually may lead to loss in nutritional value and formation of toxic products (e.g., cholesterol oxides). Today, consumers make greater demands on packaging, including transparent packaging, in order to better appraise the product prior to purchase. Furthermore, environmental concerns have caused a reduction in the use of aluminum and metallized foils. These factors have led to increased use of transparent packaging

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

materials within the entire food sector. However, packaging of dairy products in transparent materials greatly increases the risk of light-induced oxidation [42]. It is normally accepted that light-induced oxidation in dairy products is the result of the presence of riboflavin as a photosensitizer. The action of riboflavin is not clearly photodynamic, since riboflavin itself is photooxidized.

For purposes of convenience, many cheese varieties, including Cheddar or Parmigiano Reggiano [43,44], are available in a preshredded form in translucent modified atmosphere packaging [45]. Transparent films transmitting more than 80% of the incident light in the wavelength range 400–800 nm are generally used [46]. High-intensity light has been reported to have negative effects on the color stability of natural yellow cheeses. In addition, shredded Cheddar cheese stored under high-intensity fluorescent light may be susceptible to light-induced oxidation reactions. Color data for shredded Cheddar cheeses packaged under N_2 and CO_2 and stored under light or dark conditions were monitored [47]. Approximately 10 g of cheese shreds was compressed into a $50 \times 50 \times 10$ mm optical cell. Reflectance values were obtained using a 25 mm view area aperture. L^* values were significantly higher in cheeses packaged under CO_2 and exposed to fluorescent light, whereas a^* and b^* values were significantly lower. The shredded cheeses packaged under CO_2 and exposed to fluorescent light experienced obvious color alterations during storage, shifting from the traditional orange of colored Cheddar cheese to a definite white hue. One possible explanation for the color shift in the shredded Cheddar cheese packaged under CO_2 and exposed to fluorescent light is related to annatto, the pigment commonly used in the production of natural yellow cheeses such as Cheddar. Annatto extracts are obtained from the seeds of *Bixa orellana*. The carotenoid that is mainly responsible for the coloring properties of annatto is bixin, which contains numerous conjugated double bonds. Conjugated double bonds are the target of free radical molecules, leading to oxidation reactions in lipids and probably in the carotenoid, bixin. It is proposed that the color loss was due to bixin oxidation which resulted from CO_2-derived free radical species generated under light exposure.

In another study [48], salted sweet cream dairy spread was found to have better oxidative stability compared to salted sour cream dairy spread when evaluated by color changes that are measured as tristimuli L^*, a^*, b^* values. Results showed that the storage temperature (–18°C, 5°C, or 20°C) was most important as the product surface was found darker and more yellow and greenish.

Regarding yogurt color modification during postprocessing, a first study investigated the relationship between color parameters and the syneresis and titrable acidity [49]. Regardless of storage time, yogurts with an initial pH of 4.35 had the lowest L^* values, while the yogurts with an initial pH of 4.45 had the highest. Storage time exerted a significant influence on the decrease in the color lightness value. A second study dealt with the use of bio-based material polylactate (PLA) for packaging of plain yogurt [50]. Plain yogurt (3.5% fat) was stored for 5 weeks in PLA or polystyrene (PS) cups under fluorescent light (3500 lux) or in darkness. Quality changes were studied by determination of color stability and degradation of β-carotene. For light-exposed yogurts, PLA was at least as effective in preventing color changes as PS. Furthermore, losses of riboflavin and β-carotene were less in light-exposed yogurt that was packed in PLA than in PS. Thus, it was concluded that light exposure reduced the quality of plain yogurt and that PLA provided a better protection against photodegradation processes than PS.

18.5 Quality Control

The color is one of criteria which the food industry controls to make sure that the food product meets the demand of consumption and that the product is produced in a reproducible way. In some cases, the industry use indices to monitor and to control the color of the product.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

For butter, the yellowness index (YI) is a dimensionless number obtained from the tristimulus primaries *X*, *Y*, and *Z*, data available from many instrumental devices, together with the appropriately derived L^*, a^*, and b^* coordinates. YI is calculated as follows:

$$\mathrm{YI} = 100(C_X X - C_Z Z)/Y$$

where *X*, *Y*, and *Z* are the CIE tristimulus values and the coefficients depend on the illuminant and observer. YI may only be calculated for illuminants D65 and C. (illuminant D65 and observer 10°, then $C_X = 1.3013$, $C_Z = 1.1498$) – [ASTM Method E313].

As examples, the YI was 47.7 and 57.8 in case of Sommerbutter (Austria) and Kerrygold (Ireland) butter, respectively [51]. Between the butter samples, the CIELAB color difference ΔE, representing the pythagorean distance between the two data points in the L^*, a^*, b^* system according to $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, was found to be 5.9. This ΔE value is far above the sensory threshold of ~0.7, which is relevant in the range of the butter color coordinate. Quality control is important in butter production as consumers link more yellowish butter with "easier-to-spread" [52].

Determination of food authenticity and geographic origin is a crucial issue in food quality control. Adulterations are known for dairy products. The geographic origin of butter and milk, the addition of cow's milk to ewe's or goat's milk or other dairy products, and the use of added whey solids or processed cheeses in grated cheese have been reported. The originality of a cheese depends on several factors such as milk and cheese-making procedures (including microbiology and technology), which are both dependent on the geographic origin. The determination of origin is a key component of PDO products and, where industrial copies exist, of goods manufactured by a traditional method. Emmenthal (Emmentaler) cheese, often called "Swiss cheese" is the example "par excellence" of a cheese variety that is widespread and very popular in many countries. Color measurement was included in a study that aimed to evaluate the potential of a large variety of analytical methods for determining the geographic origin of an Emmentaler cheese [53]. In Emmenthal cheeses collected in five countries (Germany, Austria, Finland, France, and Switzerland), the parameters a^* and b^* presented considerable differences. The Finnish Emmentaler was significantly redder and yellower than the others. "French Savoie," on the other hand, was significantly less yellow than the others and "French Bretagne" more blue. A possible explanation may be found in the forage. "Finland" uses grass silage whereas "French Bretagne" feeds maize silage. In the other regions, silages are not permitted.

The control of the color of dairy products is particularly attractive with several dessert product varieties. Due to the possibility to vary the concentration of fruit preparations as well as natural and artificial dyes added, the color properties (hue, saturation, brightness) can be chosen deliberately within certain limits. As to yogurt-based desserts, color plays a dominant role in influencing the purchasing behavior of consumers. For example, a sharp drop of consumption was observed with fruit-flavored yogurts when they were marketed without added colorants, proving the influence of color on identification and acceptance of the product [54]. It is well documented that the color of fruit yogurts and related products may be influenced by several technological parameters such as fat content, heating and storage conditions and, basically, by the amount of fruits added. Recommendations concerning the concentration of fruit preparations as given by the manufacturers of these food ingredients are not only based on sensory attributes, but also aim at obtaining a distinct coloration of the final product [1]. With regard to the instrumental measurements of color,

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

it can be reported that as the concentration of colorant increased, the L^* parameter decreased. In the case of a lemon-flavored yogurt, a^* decreased and b^* increased; in the yogurts with strawberry and fruit of the forest flavors, a^* increased and b^* decreased; and in the orange-flavored yogurts, both a^* and b^* increased as the concentration of colorant increased [55]. These results are as expected, since the parameter that determines red is a^* and the one that determines yellow is b^*. Colorant concentration may also have an influence on the perception of the intensity of flavor and sweetness and this a an additional reason to control this point.

In yogurts or other dairy foods, native natural and added natural or artificial colorants could be analyzed using HPLC with photodiode array detection. Carotenoids and other pigments have been extensively investigated, such as β-carotene (E160a(ii)), β-apo-8′-carotenal (E160e) [56], bixin and bixin derivatives [57], copper chlorophyll (E141(i)) and chlorophyllin (E141(ii)) [58], or synthetic colors [59]. Each pigment is then characterized by its retention time and absorption spectrum [38,60]. The main drawback with dairy foods is that they are quite rich in fat, so sample preparation is important and extraction of pigments requires either saponification step or treatment with enzymes such as lipase or phospholipase. Extraction and HPLC methods should also be able to estimate if the levels of colorants are well below the maximum levels specified in the European Council Directive (94/36 EC), linked, in some cases, to acceptable daily intakes.

A robust and automatic sample screening system that provides a reliable response to natural or synthetic colorants in dairy samples with minimal pretreatment of samples was developed; the binary response is related to the detection limit of the method (6–15 or 25–10 000 ng/mL for synthetic or natural colorants, respectively). If it gives a positive result, the sample is analyzed with the discrimination method. This method discriminates among mixtures of colorants of the same or different colors. In addition, each colorant can be identified by its absorption spectrum using the LC–DAD method [10] (Table 18.1). Another study focused on the use of HPLC for "carotenoid food additives" analysis [61].

Some pigments not only have coloring properties but could also have some beneficial impact on health. For example, lutein has been identified as a dietary factor that can delay the onset of age-related macular degeneration (AMD). Food fortification with lutein extract has been identified as a low-budget approach to prevent the onset or progression of AMD. Lutein was then incorporated in various amounts in Cheddar cheese [62] or strawberry yogurt [63], the color of the products monitored, and the stability of lutein during the process and maturation analyzed by HPLC. The results indicate that lutein, a functional additive with purported ability to prevent or reduce the onset of AMD, can be incorporated into dairy foods adding value to these products.

18.6 Conclusion

The purpose of this chapter was to demonstrate the potential inherent in objective color measurement of dairy products. The panel of methods is quite large and these methods are applied to numerous different dairy products, from the production of milk itself to the monitoring of the shelf life of yogurts or cheeses. Tristimulus color reflectance measurement is a tool which can be utilized to obtain well-defined physical data and such technique will see its use improved with some developments in metrology, in order to develop international standards or norms dedicated to milk and dairy products.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 18.1 Application of the Screening and Discrimination LC–DAD Methods to Dairy Samples

Sample	*Colorants That Appear on Label*		*Screening Response*[a]		*Concentration Found by LC–DAD*[a]
			Synthetic	*Natural*	
Yogurt					
Lemon	Natural yellow	Curcumin	Negative	Positive	172 ± 9
Peach	Natural yellow	Curcumin	Negative	Positive	205 ± 10
	Natural red	Carminic acid	Negative	Positive	18.5 ± 0.7
Strawberry	Natural red	Carminic acid	Negative	Positive	22 ± 1
Nuts and oats	Natural brown	Caramel	Negative	Positive	653 ± 40
Pineapple	Natural yellow	*Trans*-β-carotene	Negative	Positive	44 ± 2
Apricot and mango	Natural yellow	Curcumin	Negative	Positive	250 ± 12
	Natural yellow	*Trans*-β-carotene	Negative	Positive	42 ± 2
Ice cream					
Iced lemon fruit	Synthetic yellow	Tartrazine	Positive	Negative	6.8 ± 0.3
	Synthetic green	Lissamine green B	Positive	Negative	1.6 ± 0.1
Lemon	Synthetic yellow	Tartrazine	Positive	Negative	38 ± 2
Pistachio	Synthetic yellow	Tartrazine	Positive	Negative	28 ± 1
	Synthetic blue	Indigo carmine	Positive	Negative	14.8 ± 0.9
Vanilla	Natural yellow	Riboflavin	Negative	Positive	51 ± 2
	Natural yellow	*Trans*-β-carotene	Negative	Positive	30 ± 2

(*continued*)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 18.1 (continued) Application of the Screening and Discrimination LC–DAD Methods to Dairy Samples

Sample	*Colorants That Appear on Label*		*Screening Response*[a]		*Concentration Found by LC–DAD*[a]
			Synthetic	*Natural*	
Fruits	Natural yellow	Riboflavin	Negative	Positive	50 ± 2
	Natural yellow	*Trans*-β-carotene	Negative	Positive	37 ± 2
	Natural red	Carminic acid	Negative	Positive	26 ± 1
Milk shake					
Vanilla 1	Natural yellow	Curcumin	Negative	Positive	85 ± 4
	Natural red	Carminic acid	Negative	Positive	24 ± 1
Vanilla 2	Natural yellow	Riboflavin	Negative	Positive	66 ± 3
	Natural yellow	*Trans*-β-carotene	Negative	Positive	23 ± 1
Strawberry	Natural red	Carminic acid	Negative	Positive	24 ± 1
Dairy dessert					
Yogurt flavor	Synthetic yellow	Tartrazine	Positive	Negative	5.3 ± 0.3
	Synthetic blue	Indigo carmine	Positive	Negative	1.8 ± 0.1

Source: Adapted from Gonzalez, M. et al., *Anal. Chem.*, 75, 685, 2003. With permission.

[a] Average values ± standard deviation ($n = 6$) in mg/kg food.

References

1. Ulberth, F., Kneifel, W., and Schaffer, E. Colour intensity preferences observed with selected fruit yogurts. *Milchwissenschaft*, 48: 15–17, 1993.
2. Anonymous. *Precise Color Communication. Color Control, from Perception to Instrumentation*, Konica-Minolta Sensing Inc., Japan, 59 pp., 1998.
3. CIE. Compagnie Internationale de l'Eclairage, 1978. International Commission on Illumination, Recommendations on uniform color spaces. Supplement No. 2 to CIE Publication No. 15.2, Bureau Central, Paris.
4. Álvarez-Moro, C. and Heredia-Mira, F. J. PCROM: Cálculos colorimétricos, v.2.0. Spanish Patent SE-2374, 1994.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

5. Pillonel, L. et al. Prediction of colour of European Emmental cheeses by using near infrared spectroscopy: A feasibility study. *Eur. Food Res. Technol*., 226: 63–69, 2007.
6. McCaig, T. N. Extending the use of visible/near-infrared reflectance spectrophotometers to measure colour of food and agricultural products. *Food Res. Int*., 35: 731–736, 2002.
7. Chatelain, Y. et al. La couleur du lait et des produits laitiers et sa mesure: un article de synthèse (1972–2002). *Mitt. Lebensm. Hyg*., 94: 461–488, 2003.
8. Kneifel, W., Ulberth, F., and Chaffer, E. Tristimulus colour reflectance measurement in milk and dairy products. *Lait*, 72: 383–391, 1992.
9. Wang, H. H. and Sun D. W. Assessment of cheese browning affected by baking conditions using computer vision. *J. Food Eng*., 56: 339–345, 2003.
10. Gonzalez, M., Gallego, M., and Valcarcel, M. Determination of natural and synthetic colorants in prescreened dairy samples using liquid chromatography-diode array detection. *Anal. Chem*., 75: 685–693, 2003.
11. Nozière, P. et al. Carotenoids for ruminants: From forages to dairy products. *Anim. Feed Sci. Tech*., 131: 418–450, 2006.
12. Solah, V. A. et al. Measurement of milk color and composition: Effect of dietary intervention on Western Australian Holstein-Friesian cow's milk quality. *J. Food Sci*., 72: S560–S566, 2007.
13. Schreiner, M. and Windisch, W. Supplementation of cow diet with rapeseed and carrots: Influence on fatty acid composition and carotene content of the butter fat. *J. Food Lipids*, 13: 434–444, 2006.
14. Rohm, H. and Jaros, D. Color of hard cheese. 1: Description of color properties and effects of maturation. *Z. Lebensm. Unters. Forsch*., 203: 241–244, 1997.
15. Casalis, J. Y. et al. Sur la relation entre la teneur en beta-carotene et la couleur des beurres français. *Lait*, 52: 28–42, 1972.
16. Berl, S. and Peterson, W. H. Distribution of carotene and vitamin A in butter-making. *J. Dairy Sci*., 28: 103–107, 1945.
17. Gokturuk, S. et al. Effects of season on vitamins A and E contents and colour of Turkish butter. *Nahrung/Food*, 46: 54–55, 2002.
18. Lucas, A. et al. Respective effects of milk composition and the cheese-making process on cheese compositional variability in components of nutritional interest. *Lait*, 86: 21–41, 2006.
19. Datta, N. and Deeth, H.-C. High pressure processing of milk and dairy products. *Aust. J. Dairy Technol*., 54: 41–48, 1999.
20. Hayes, M., Fox, P. F., and Kelly, A. L. Potential applications of high pressure homogenisation in processing of liquid milk. *J. Dairy Res*., 72: 25–33, 2005.
21. Capellas, M. et al. Effect of high-pressure processing on physico-chemical characteristics of fresh goats' milk cheese (Mato). *Int. Dairy J*., 11: 165–173, 2001.
22. Quinones, H.-J., Barbano, D. M., and Phillips, L. G. Influence of protein standardization by ultrafiltration on the viscosity, color, and sensory properties of skim and 1% milk. *J. Dairy Sci*., 80: 3142–3151, 1997.
23. Quinones, H.-J., Barbano, D. M., and Phillips, L. G. Influence of protein standardization by ultrafiltration on the viscosity, color, and sensory properties of 2 and 3.3% milks. *J. Dairy Sci*., 81: 884–894, 1998.
24. Gonzalez-Martinez, C. et al. Influence of substituting milk powder for whey powder on yoghurt quality. *Trends Food Sci. Tech*., 13: 334–340, 2002.
25. Friedeck, K. G., Karagul-Yuceer, Y., and Drake, M. A. Soy protein fortification of a low-fat dairy-based ice cream. *J. Food Sci*., 68: 2651–2657, 2003.
26. Rudan, M. A., Barbano, D. M., and Kindstedt P. S. Effect of fat replacer (Salatrim®) on chemical composition, proteolysis, functionality, appearance, and yield of reduced fat Mozzarella cheese. *J. Dairy Sci*., 81: 2077–2088, 1998.
27. Roland, A. M., Phillips, L. G., and Boor, K. J. Effects of fat replacers on the sensory properties, color, melting, and hardness of ice cream. *J. Dairy Sci*., 82: 2094–2100, 1999.
28. Aryana, K. J. and Beck, M. C. Properties of low fat Cheddar cheese manufactured with chitosan. *Milchwissenschaft*, 62: 39–43, 2007.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

29. Garcia-Perez, F. et al. Effect of orange fiber addition on yogurt color during fermentation and cold storage. *Color Res. Appl*., 30: 457–463, 2005.
30. Bertelli, L., Torreggiani, D., and Bertolo, G. Non-enzymatic browning in hydrolysed concentrated cheese whey permeate. *Food Chem*., 55: 353–358, 1996.
31. Yann, D., Didier, H., and Daniel, B. Utilisation of the experimental design methodology to reduce browning defects in hard cheeses technology. *J. Food Eng*., 68: 481–490, 2005.
32. Metzger, L. E. et al. Whiteness change during heating and cooling of Mozzarella cheese. *J. Dairy Sci*., 83: 1–10, 2000.
33. Agabriel, C. et al. Tanker milk variability according to farm feeding practices: Vitamins A and E, carotenoids, color, and terpenoids. *J. Dairy Sci*., 90: 4884–4896, 2007.
34. Kristensen, D. et al. Influence of light and temperature on the colour and oxidative stability of processed cheese. *Int. Dairy J*., 11: 837–843, 2001.
35. Dufossé, L. et al. Spectrocolorimetry in the CIE L*a*b* color space as useful tool for monitoring the ripening process and the quality of PDO red-smear soft cheeses. *Food Res. Int*., 38: 919–924, 2005.
36. Dufossé, L., Mabon, P., and Binet, A. Assessment of the coloring strength of *Brevibacterium linens* strains: Spectrocolorimetry versus total carotenoid extraction/quantification. *J. Dairy Sci*., 84: 354–360, 2001.
37. Guyomarc'h, F., Binet, A., and Dufossé, L. Characterization of *Brevibacterium linens* pigmentation using spectrocolorimetry. *Int. J. Food Microbiol*., 57: 201–210, 2000.
38. Galaup, P. et al. HPLC analysis of the pigments produced by the microflora isolated from the "Protected Designation of Origin" French red-smear soft cheeses Munster, Epoisses, Reblochon and Livarot. *Food Res. Int*., 38: 855–860, 2005.
39. Leclercq-Perlat, M. N., Corrieu, G., and Spinnler, H.E. The color of *Brevibacterium linens* depends on the yeast used for cheese deacidification. *J. Dairy Sci*., 87: 1536–1544, 2004.
40. Masoud, W. and Jakobsen, M. Surface ripened cheeses: The effects of *Debaryomyces hansenii*, NaCl and pH on the intensity of pigmentation produced by *Brevibacterium linens* and *Corynebacterium flavescens*. *Int. Dairy J*., 13: 231–237, 2003.
41. Mounier, J. et al. Growth and colour development of some surface ripening bacteria with *Debaryomyces hansenii* on aseptic cheese curd. *J. Dairy Res*., 73: 441–448, 2006.
42. Mortensen, G. et al. Light-induced changes in packaged cheeses: A review. *Int. Dairy J*., 14: 85–102, 2004.
43. Romani, S. et al. Physical, chemical, textural and sensorial changes of portioned Parmigiano Reggiano cheese packed under different conditions. *Food Sci. Technol. Int*., 8: 203–211, 2002.
44. Severini, C. et al. Physical and chemical changes in vacuum packaged Parmigiano Reggiano cheese during storage at 25, 2 and –25°C. *J. Food Qual*., 21: 355–367, 1998.
45. Juric, M. et al. Light-induced colour and aroma changes in sliced, modified atmosphere packaged semi-hard cheeses. *Int. Dairy J*., 13: 239–249, 2003.
46. Mortensen, G., Sorensen, J., and Stapelfeldt, H. Light-induced oxidation in semihard cheeses. Evaluation of methods used to determine levels of oxidation. *J. Agric. Food Chem*., 50: 4364–4370, 2002.
47. Colchin, L. M. et al. Modified atmosphere packaged Cheddar cheese shreds: Influence of fluorescent light exposure and gas type on color and production of volatile compounds. *J. Agric. Food Chem*., 49: 2277–2282, 2001.
48. Kristensen, D. et al. Oxidative and colour stability of salted sour cream dairy spread compared to salted sweet cream dairy spread. *Milchwissenschaft*, 55: 504–507, 2000.
49. Cais-Sokolinska, D. and Pikul, J. Use of colour measurement to evaluate yoghurt quality during storage. *Ital. J. Food Sci*., 18: 63–71, 2006.
50. Strand-Frederiksen, C. et al. Light-induced quality changes in plain yoghurt packed in polylactate and polystyrene. *Eur. Food Res. Technol*., 217: 61–69, 2003.
51. Rohm, H., Strobl, M., and JAROS, D. Butter colour affects sensory perception of spreadability. *Food Res. Technol*., 205: 108–110, 1997.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

52. Krause, A. J., Lopetcharat, K., and Drake, M. A. Identification of the characteristics that drive consumer liking of butter. *J. Dairy Sci*., 90: 2091–2102, 2007.
53. Pillonel, L. et al. Analytical methods for the determination of the geographic origin of Emmentaler cheese. Main framework of the project: Chemical, biochemical, microbiological, colour and sensory analysis. *Eur. Food Res. Technol*., 215: 260–267, 2002.
54. Calvo, C., Salvador, A. and Fuszman, S. M. Influence of colour intensity on the perception of colour and sweetness in various fruit-flavoured yoghurts. *Eur. Food Res. Technol*., 213: 99–103, 2001.
55. Gambaro, A., Gimenez, A., and Burgueno J. Sensory and instrumental evaluation of strawberry yogurt color. *J. Sens. Stud*. 16: 11–22, 2001.
56. Scotter, M. J. et al. Method development and analysis of retail foods and beverages for carotenoid food colouring materials E160a(ii) and E160e. *Food Addit. Contam*., 20: 115–126, 2003.
57. Lancaster, F. E. and Lawrence, J. F. Determination of annatto in high-fat dairy products, margarine and hard candy by solvent extraction followed by HPLC. *Food Addit. Contam*., 12: 9–19, 1995.
58. Scotter, M., Castle, L., and Roberts, D. Method development and HPLC analysis of retail foods and beverages for copper chlorophyll (E141[i]) and chlorophyllin (E141[ii]) food colouring materials. *Food Addit. Contam*., 22: 1163–1175, 2005.
59. Tripathi, M. K., Khanna, S. K., and Das, M. A novel method for the determination of synthetic colors in ice cream samples. *J. AOAC Int*., 87: 657–663, 2004.
60. Galaup P. et al. First pigment fingerprints from the rind of French PDO red-smear ripened soft cheeses Epoisses, Mont D'Or and Maroilles. *Innovat. Food Sci. Emerg. Technol*., 8: 373–378, 2007.
61. Breithaupt, D. E. Simultaneous HPLC determination of carotenoids used as food coloring additives: Applicability of accelerated solvent extraction. *Food Chem*., 86: 449–456, 2004.
62. Jones, S. T., Aryana, K. J., and Losso J. N. Storage stability of lutein during ripening of Cheddar cheese. *J. Dairy Sci*., 88: 1661–1670, 2005.
63. Aryana, K.-J. et al. Lutein is stable in strawberry yogurt and does not affect its characteristics. *J. Food Sci*. 71: S467–S472, 2006.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 19

Texture

Kasiviswanathan Muthukumarappan and
Chinnadurai Karunanithy

Contents

19.1 Introduction 341
19.2 Factors Affecting Texture of Dairy Foods 342
19.3 Definitions of Texture Parameters 343
19.4 Texture Profile Analysis 344
19.5 Texture Measurement of Dairy Foods 345
19.5.1 Cheese 345
19.5.2 Butter 345
19.5.3 Yogurt 346
19.6 Sensory Measurements 347
19.7 Viscosity Measurement of Dairy Foods 347
19.7.1 Capillary Tube Viscometer 349
19.7.2 Rotational Viscometer 349
19.8 Selection of Suitable Test for Dairy Foods 349
References 350

19.1 Introduction

Texture of any dairy food is highly subjective. "Eating quality" of foods encompasses many properties of foods that excite our senses of sight, touch, and sound. Texture plays a key role in consumer acceptance and market value of many foods. There are several definitions available in the literature to define "texture." For example, The International Organization for Standardization [1]

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

defines food texture as "all the rheological and structural (geometric and surface) attributes of the product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors." There is a vast range in textural characteristics of different dairy foods: the firmness, graininess, and spreadability of butter; firmness, cohesiveness, and springiness of cheese; coarseness, butteriness, sandiness, and crumbliness of ice cream; stickiness of milk powder; viscosity of yogurt and many others. This great range of types of textural properties found in dairy foods arises from the human demand for variety in the nature of their food.

Texture means different things to different people, and the perceived textural characteristics expected from different dairy foods vary widely. In general, the food texture is evaluated using instrumental and sensory methods [2,3]. The perceived textural attributes of a given dairy food are influenced by a variety of factors such as how we chew the food and how much chewing force is applied. Given this complexity, it is very difficult, if not impossible, to objectively measure and characterize texture. Therefore, human sensory evaluation has been the cornerstone of food texture characterization. Humans are particularly sensitive in identifying textural differences between two samples, whereas instruments can quickly provide a quantitative measurement on an absolute scale. Owing to limitations of cost and variety of new dairy food, efforts are continually made in designing instrumental methods for texture evaluation. These range from simple penetrometers to measure firmness to sophisticated texture analyzers/rheometers to characterize different dairy foods. In this chapter, our focus is primarily on the measurement of perceived textural attributes of different dairy foods.

19.2 Factors Affecting Texture of Dairy Foods

Texture is the primary quality attribute of any dairy food. In most cases, the overall appearance and texture (mouthfeel) of dairy foods are appreciated ahead of other attributes such as flavor. Microstructure of dairy foods plays a key role in forming the texture [4]. The texture is a reflection of its structure at the molecular level. Casein matrix is the major structure-forming constituent in most of the dairy foods in which fat globules are entrapped and serum or water is both bound to casein and fills interstices of the matrix [5]. This matrix structure is critically affected by the relative content of protein, fat, and water, as well as by the biochemical activities that occur during storage.

All the dairy foods are manufactured from milk. During their manufacture, several factors can contribute to the texture such as temperature, process time, acidity, and pH. Low acidity weakens the protein bonds through charge repulsion, as the negative charges on casein molecules increase with pH. The hydrophobic interactions, important for a stable casein matrix structure, are weakened by adsorption of water by proteins to solvate the ionic charges.

Different cheese varieties have a wide range of textural characteristics, and these also greatly change with aging owing to proteolysis, moisture loss, salt uptake, pH change, and the slow dissolution of residual Ca associated with casein particles. Cheese composition (i.e., moisture, protein, fat, NaCl, milk salts, and pH) has a major impact on the body and texture of cheese. Cheese composition is mainly controlled by the initial composition of the cheese milk (which is modified by the method used for milk standardization) and the manufacturing protocols (e.g., pH at renneting and draining, size of curd particles, cooking temperature, method of salting) used for cheese-making. Factors such as species and breed of animal, stage of lactation, and seasonality can all affect the initial milk composition and alter the texture of cheese [6]. It is worth taking a look at

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

different reviews on the texture, rheology, and fracture properties of cheese by International Dairy Federation [7], Prentice et al. [8], and Fox et al. [9].

When it comes to yogurt, various factors such as total solids, milk composition, homogenization, type of culture, acidity, degree of proteolysis, and heat pretreatment of milk influence the rheological properties of yogurt [10–13]. Yogurt is a non-Newtonian pseudoplastic material, with a highly time-dependent behavior. Texture is one of the most important characteristics that define the quality of yogurt and affects its appearance, mouthfeel, and overall acceptability. The most frequent defects related to yogurt texture, leading to consumer rejection, are apparent viscosity variations and the occurrence of syneresis [14]. These changes may be due to variations in milk composition, as well as changes in processing, incubation, and storage conditions. Yogurt texture characterization is important for product and process development, quality control, and to ensure consumer acceptability [15]. This characterization can be done using either instrumental or sensory measurements.

19.3 Definitions of Texture Parameters

Texture, which comes from Latin *textura* (cloth), was used initially to describe the cross-linking style of weave threads. It now defines disposition and arrangement for the different parts of a system. Texture can be defined as the sensory manifestation of structure of the food and manner in which this structure reacts to the applied forces, the specific senses involved being vision, kinesthetics, and hearing [16]. Rheology and structure of a product evaluated by instrumental methods also give relevant information on its textural properties, even if sensory and instrumental data are not always easily correlated [17]. Dairy products have several important textural properties as listed in Table 19.1.

Table 19.1 Definitions of Textural Properties Pertaining to Dairy Foods

Textural Properties	*Definition*
Adhesiveness	Work necessary to overcome the attractive forces between the dissimilar materials, i.e., food surface and the food contact surface.
Chewiness	Energy required for masticating a solid food material until it is ready for swallowing.
Cohesiveness	The strength of the internal bonds making up the body of the product or degree to which the sample deforms before rupture.
Gumminess	Energy required to disintegrate a semisolid food material to a state of ready for swallowing.
Hardness	Force necessary to attain a given deformation.
Resilience	How well a product fights to regain its original position.
Springiness	Degree or rate at which the sample returns to its original shape/size after partial compression between tongue and palate.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

19.4 Texture Profile Analysis

The first texturometer was developed at General Food Corporation. This texturometer comprises a reciprocating motion that imitates the action of jaw, i.e., biting the food twice. Technology development and understanding of the food materials lead to the development of the present-day texture analyzer, which is essentially a uniaxial compression test. A number of textural parameters can be extracted from the resulting force–time curve, which correlates well with the sensory evaluation of those parameters [18]. To simulate the first two bites taking place during the chewing of food, texture profile analysis (TPA) test is performed by subjecting a cylindrical or cube specimen to a two-step compression.

A typical TPA curve of a reduced fat cheese obtained from texture analyzer (TA.XT plus Stable Micro System, New York) is used to illustrate the principles involved in TPA test (Figure 19.1). A cylindrical cheese sample (20 mm height and 17 mm diameter) was placed on the base plate, compressed, and decompressed twice by a probe attached to the drive system at 50 mm/min crosshead speed and 70% compression. Textural parameters such as hardness, springiness, cohesiveness, and gumminess were determined from the TPA curve. Hardness (F2 = 10.49 N) is determined as the peak force in the first bite curve. Springiness (4.88 mm) is calculated as the distance recovered by the sample during the time between the end of the first bite and the start of the second bite. Cohesiveness (0.674) is calculated as the ratio of the positive areas under the second bite to the first bite (area 4–6/area 1–3). Gumminess (7.07 N) is defined as the product of hardness and cohesiveness. Generally, gumminess and chewiness are derived from the measured parameters. Chewiness is defined as the product of gumminess and springiness. Either chewiness or gumminess should be reported depending on the type of dairy product [19]. Resilience (0.57) is calculated as the ratio of positive area under 1–2 to 2–3 in the first bite.

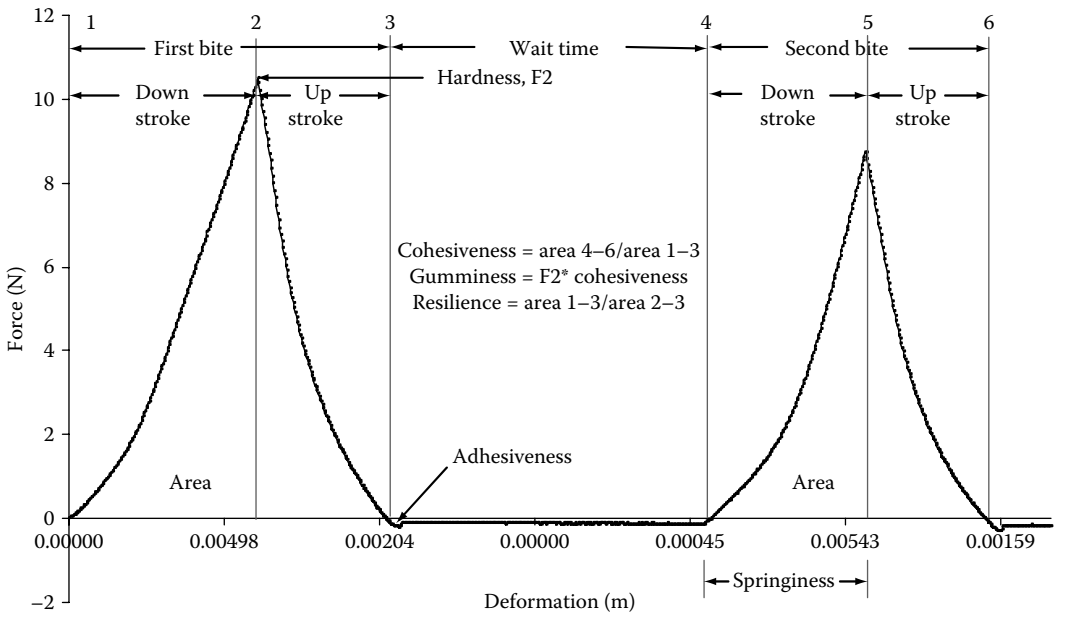


Figure 19.1 TPA of reduced fat cheese.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Fracturability is defined as the force of a significant break in the first bite curve (not shown in Figure 19.1). Adhesiveness is defined as the work necessary to overcome the attractive forces between the surface of the dairy product and the surface of the probe, and it is calculated from the negative force area of the first bite, which can be observed from the TPA curve of cheese.

19.5 Texture Measurement of Dairy Foods

Texture measurement techniques are either subjective by trained panel or objective using an instrument, i.e., fundamental, empirical, or imitative. Fundamental tests measure well-defined textural/rheological parameters. They are generally slow to perform and use expensive equipment. Empirical tests are the most commonly used that measure poorly defined parameters. These are rapid, easy to perform, and use inexpensive equipments. Fundamental tests are generally restricted to homogeneous and isotropic materials. In contrast, empirical tests place fewer restrictions on geometry and composition of the material. The choice between fundamental or empirical test depends on the purpose of the experiment. Imitative tests imitate the condition to which the food material is subjected to in a real situation. An ideal texture measurement technique may include some aspects of fundamental, empirical, and imitative methods [20].

Among the several testing methods, uniaxial testing is the most popular instrumental method used for evaluating mechanical and rheological properties of solid dairy foods. International Dairy Federation [7] developed a standard for testing and reporting uniaxial test results of cheese. Uniaxial compression testing conditions of dairy foods should include shape, size (aspect ratio >1), crosshead speed, compression rate, and the temperature of sample and environment. It is better to report all original and derived results along with complete force–deformation curve [21,22]. Testing methods for cheese, butter, and yogurt are discussed here.

19.5.1 Cheese

Texture is the primary quality attribute of cheeses. For each cheese type, there is an expected dominant textural attribute: ex Mozzarella cheese is stretchy or stringy and Parmesan cheese is crumby. Cheese is a viscoelastic material, so the rate of compression and wait time between the first and second bite will affect the results. Brennan et al. [23] was the first to perform TPA on Cheddar cheese using the General Food Texturometer. The TPA is the most widely used instrumental measurement for cheese texture evaluation [24,25], which is also an imitative test. To imitate the chewing action more closely, Bourne [26] suggested a 90% compression for the TPA of cheese. However, Table 19.2 shows the variation in sample shape, size, compression rate, compression percentage, and test temperature as reported by various researchers. Viñas et al. [27] reported an increase in the hardness of Artisanal cheese during ripening time from 2 to 12 months. Nonfat process cheese hardness varied from 1.76 to 6.67 N depending on pH and the emulsifying agents used during manufacturing [28]. The hardness, springiness, and gumminess depend on the type of acid (lactic, citric, and acetic) used during manufacturing of Queso Blanco-type cheese [30].

19.5.2 Butter

Texture is one of the four quality factors that determine acceptability of butter [2]. It influences spreadability, taste, mouthfeel, appearance, and suitability of butter for various uses. The most

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Table 19.2 Variation in Cheese Texture Measurement Conditions

Measurement Conditions	*Vinas et al. [27]*	*Brickley et al. [28]*	*Everard et al. [29]*	*Farkye et al. [30]*
Sample size, mm			25 × 25 × 25	20 × 20 × 20
Height	20	17.5		
Diameter	15	16.0		
Shape	Cylinder	Cylinder	Cube	Cube
% Compression	80	80	70	50
Crosshead speed, mm/min	50	60	60	75
Wait time, s	NR	NR	3	NR
Test temperature, °C	20	4	4	NR

NR, not reported.

commonly used test to evaluate butter texture has been penetrometry [31]. Cone penetrometry with constant load is still widely used to evaluate butter texture. It offers simple and economical methods, and the results obtained correlate well with the sensory evaluation [32]. Apart from penetrometry, compression, sectility, and extrusion are other methods to evaluate the texture of butter. Spreading, biting, and chewing involve breaking down butter's structure, so large deformation tests are useful in understanding the textural properties [17]. Large deformation techniques are generally simple and rapid, and require a relatively inexpensive equipment. Mickle et al. [33] reported butter hardness as 12.16–13.53 N. Hardness and adhesiveness of butter can be determined using a TA-XT2 texture analyzer (Stable Micro Systems, London, United Kingdom). Bobe et al. [34] lowered a 40° conical probe at 1 mm/s to a depth of 12 mm from the sample surface and then withdrawn at the same speed. They reported the penetration force (in G) as hardness and the negative force–time value (in G × s) generated during probe withdrawal as adhesiveness.

19.5.3 Yogurt

Texture is a critical aspect of consumer acceptability of yogurt [35,36]. Rheological properties of yogurt have been empirically evaluated by measuring gel hardness and viscosity of stirred products. The application of nondestructive dynamic rheological methods for yogurt gels has also been reported [37–39]. Fundamental rheological testing has the advantage over empirical methods in that it reveals structural characteristics of yogurt gels, especially in set-type yogurt. Hardness of yogurt varies between 0.15 N and 0.30 N depending on the type of yogurt. A penetration test was performed to determine the gel force by Salvador and Fiszman [40] using a TA.XT. Plus Texture Analyzer (Stable Micro Systems, Godalming, United Kingdom). They made a 20 mm penetration with a 12.5 mm diameter probe with a flat base (TA/0.5) at a speed of 1 mm/s. Firmness is recorded as the force at breaking (in N), defined as the first significant discontinuity produced in the curve as the plunger penetrated the gel during a total displacement of 20 mm, and the distance at which breaking took place (in mm).

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The gel strength of yogurt made from conventionally treated milk and UHT milk fortified with low-heat skimmed milk powder was compared by Krasaekoopt et al. [41] using a texture analyzer (TA-XT2 Stable Micro Systems, United Kingdom) with 20 mm diameter perspex probe (CodeP/20P) at a speed of 1 mm/s in compression mode. A combination of back extrusion, i.e., a 35 mm diameter solid rod (A/BE35) can be thrust into the cylindrical containers holding the yogurt for texture measurements using texture analyzer TA-XT2i (Texture Technologies Corp., White Plains, New York). Sandoval-Castilla et al. [42] conducted two cycle tests on reduced fat yogurt at a constant crosshead speed of 1 mm/s to a sample depth of 30 mm depending on the fat replacers used; springiness (29.56–29.79 $\times 10^{-3}$ m), adhesiveness (140–1076 $\times$ 10^{-6} Nm), and cohesiveness (0.77–0.91) were reported in addition to tension (87–145.69 $\times$ 10^{-3} N—the first drop in force during sample penetration) and firmness (112–177.33 $\times$ 10^{-3} N—maximum force as the test cell penetrated 30 mm of penetration into the sample) as described by Mohamed and Morris [43].

Ozer et al. [44] compared the effectiveness of destructive (conventional rheological techniques) and the nondestructive (oscillatory dynamic) test for the study of the physical properties of concentrated yogurt (labneh). Dynamic rheological studies revealed that labneh is a viscoelastic system in which its elastic characteristic is more dominant than its viscous properties. The elastic and viscous attributes of the control labneh were significantly different from the rest of the test samples. The destructive techniques (penetrometer and viscometer) failed to reveal the expected differences between the samples, and the results did not correlate with the oscillatory dynamic tests. They suggested that dynamic studies are much more reliable than the destructive rheological techniques for the study of the physical properties of labneh.

19.6 Sensory Measurements

Sensory measurements are classified as consumer acceptance taste tests and trained panel taste tests. The consumer acceptance taste tests are frequently conducted in shopping malls, supermarkets, laboratory, and other areas having a large number of consumers. The purpose of these tests is to obtain a general evaluation of consumer acceptance or rejection of a dairy product. On the other hand, the trained panel taste tests are conducted by professionals with experience in sensory evaluation techniques. The panelists are trained to detect specific food characteristics such as firmness, flavor, graininess, spreadability, cohesiveness, springiness, coarseness, butteriness, sandiness, crumbliness, and stickiness with high degree of reproducibility. There is a wide variation between trained panels in their ability to detect individual food characteristics. In general, the results from consumer acceptance taste tests are essentially qualitative and the results from the trained panel tests are quantitative. Often the results from the trained panel tests are correlated with those obtained from instrumental methods as means of comparison.

19.7 Viscosity Measurement of Dairy Foods

The viscosity describes the resistance of the internal liquid layers to shear. From everyday use, we know that "thick" liquids like grease and glycerin have a high viscosity, whereas "thin" liquids like milk and water have a low viscosity. Usually, fluids obey the following law:

$$\text{shear stress} = -\text{viscosity} \times \text{shear rate}$$

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

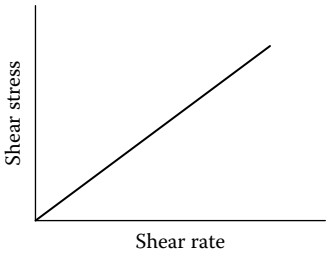


Figure 19.2 Relationship between shear stress and shear rate for Newtonian liquids.

Fluids that obey this relationship are called "Newtonian fluids." In other words, Newtonian fluids are fluids in which the shear rate is directly proportional to the shear force (Figure 19.2). To simplify things, consider that when liquid flows, the liquid layers are actually sliding against one another. The shear stress is a measure of the forces breaking the liquid layers apart, while the shear rate is a measure of how fast the liquid layers slide against one another. Viscosity is usually represented by the symbol μ.

The fluids that do not obey the above relationship are called non-Newtonian fluids, so the viscosity is a variable, not a constant. For non-Newtonian fluids, the relationship between shear stress and shear rate is nonlinear, as shown in Figure 19.3. There are two important types of non-Newtonian liquids, namely shear-thinning liquids and shear-thickening liquids. The differences between these two types of liquids can be understood easily by the term "apparent viscosity." For a shear-thinning liquid, as the shear rate increases the corresponding apparent viscosity decreases; therefore, the name shear thinning is used to describe the behavior of these liquids. On the other hand, if the increase in shear rate results in an increase in apparent viscosity, then the liquid is called a shear-thickening liquid. Non-Newtonian fluids are of great interest as they encompass almost all dairy fluids of industrial value. In the dairy industry, even a natural product such as milk is non-Newtonian.

To successfully measure non-Newtonian fluids, a known shear field (preferably constant) must be generated in the instrument. Generally, this situation is known as steady simple shear. There are two types of instruments typically used to measure the apparent viscosity of different dairy products that are non-Newtonian. They are

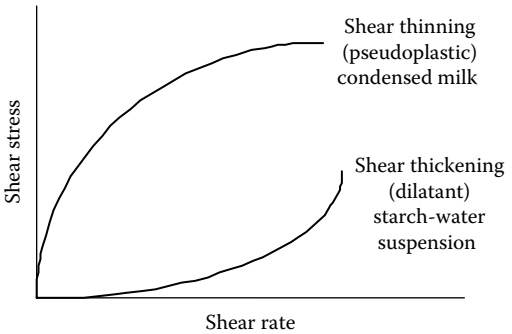


Figure 19.3 Relationship between shear stress and shear rate for non-Newtonian liquids.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

19.7.1 Capillary Tube Viscometer

In this instrument, the fluid flows inside a tube of known length. The decrease in the fluid pressure over the specified length is used to calculate the viscosity. For liquids with high viscosity, the pressure drop is high, whereas for liquids with low viscosity, the pressure drop is low.

19.7.2 Rotational Viscometer

Rotational viscometers are the most commonly used. To meet the criterion of steady simple shear, cone and plate, parallel plates, or concentric cylinders are used. The concentric cylinders instrument has two cylinders, one placed inside the other so that there is a narrow fixed gap between them. The liquid whose viscosity is to be measured is placed in the gap. One of the cylinders is rotated, the force required to rotate it is measured and related to the viscosity. If the fluid has a high viscosity, the force needed for rotation will be high; if the viscosity is low, the force will be low. Rotational viscometers generally have a fixed range of measurement owing to the limitations of their drive systems (motors). Viscometers typically generate viscosity data over a linear range of one to three orders of magnitude of shear rate and a specialized viscometer is called a rheometer. This special device is used to characterize viscoelasticity of any dairy product such as cheese, yogurt, ice cream, butter, and whipped cream. But this device can be used to measure viscosity alone. These devices are more expensive than normal viscometers, but can measure viscosity over wider ranges of shear rate or shear stress. This means that the processing engineer or new product developer has access to more information.

19.8 Selection of Suitable Test for Dairy Foods

A number of factors should be considered before setting up a new test procedure. They are: nature of the product, purpose of test, accuracy required, destructive or nondestructive, cost, time, and location. The first decision is whether to use an instrument or sensory test. Instruments have advantages being more reproducible, and use less time and labor. There are different kinds of dairy products—liquid, solid, homogeneous, heterogeneous, and plastic or viscoelastic, which affects the type of instrument selection [26].

The purpose of test may be for basic research, quality control, new product development, or legal standards, which influences the selection process. Single or multipoint measurement should be selected based on the purpose of test. Sophisticated instrument is required for new product development or research laboratory, which deals with difficult problems. Generally, large sample size gives a value closer to true mean than the small sample size. However, higher accuracy is obtained as the number of replications is more. Large sample size means higher forces are needed, which dictates the force capacity of the instrument [26].

Basically, destructive tests ruin the structure of the sample, making it unsuitable to repeat the test with the same sample. Nondestructive test offers the advantages of the same sample being used for repeated testing. Dairy food textural parameters are sensed in mouth, and mastication is a destructive process; so it is logical that destructive tests are the predominant test types.

Wide range of test accessories such as easily mountable probes, grips, anvils, and fixtures (penetration, cylinders, compression platform, warner bratzler blade, krammer shear cell, pasta hardness and stickiness rigs, dough stickiness, kieffer dough extensibility rig, etc.) should be available. User-friendly software that allows stand-alone programs to run all standard tests on foods and allow flexibility for changing test and measurement of configurations should be considered [45].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Cost per sample analysis is another factor in test selection process. It is normally arrived from initial instrument cost, maintenance, and operating costs. One has to strike a balance between automatic/sophisticated or manually operated; again it depends on the volume of the sample. In an industry, quick or timely sample analysis is required, whereas in a research laboratory, time is not a critical factor. The place of instrument location influences the test selection process. If the instrument is to be used in plant condition, it should withstand steam, water, dust, vibration, etc. If the industry has a plan to expand its product range in future, additional fixtures may be considered during the selection process. Each of these principles has been successful in quantifying the texture of some products but none of them has been successful with all the products.

References

1. ISO 5492. *Sensory Analysis—Vocabulary*. International Organization for Standardization, Geneva, Switzerland, 1992.
2. Bourne, M.C. *Food Texture and Viscosity: Concept and Measurement*. Academic Press. New York, 2002.
3. Rosenthal, A.J. Relation between instrumental and sensory measures of texture, in Rosenthal, A.J., (ed.), *Food Texture, Measurements and Perception*. Aspen Publishers, Inc., Gaithersburg, MD, 1999, pp. 1–17.
4. Aguilera, J.M. and Stanley, D.W. *Microstructural Principles of Food Processing and Engineering*, 2nd edn. Aspen Publishers, Inc., Gaithersburg, MD, 1999.
5. Hort, J. and Grys, G.L. Developments in the textural and rheological properties of UK Cheddar cheese during ripening. *Int. Dairy J*., 11(4–7), 475, 2001.
6. Lucey, J.A., Johnson, M.E., and Horne, D.S. Perspectives on the basis of the rheology and texture properties of cheese. *J. Dairy Sci*., 86, 2725, 2003.
7. International Dairy Federation. *Rheological and Fracture Properties of Cheese*. Bull. IDF No. 268, International Dairy Federation, Brussels, Belgium. 1991.
8. Fox, P.F. et al. *Fundamentals of Cheese Science*. Aspen publishers, Inc., Gaithersburg, MD, 2000.
9. Prentice, J.H., Langley, K.R., and Marshall, R.J. Cheese rheology, in Fox, P.F., (ed.), *Cheese: Chemistry, Physics and Microbiology*. Elsevier Applied Science Publishing Co., London, U.K., 1993, vol. 1, pp. 303–340.
10. Harwalkar, V.R. and Kalab, M. Relationship between microstructure and susceptibility to syneresis in yogurt made from reconstituted nonfat dry milk. *Food Microstruct*., 5, 287, 1986.
11. Heertje, I., Visser, J., and Smits, P. Structure formation in acid milk gels. *Food Microstruct*., 4, 267, 1985.
12. Kalab, M., Allan-Wojtas, P., and Phipps-Todd, B.E. Development of microstructure in set-style nonfat yogurt—A review. *Food Microstruct*., 2, 51, 1983.
13. Biliaderis, C.G., Khan, M.M., and Blank, G. Rheological and sensory properties of yogurt from skim milk and ultrafiltered retentates. *Int. Dairy J*., 2, 311, 1992.
14. Kroger, M. Quality of yogurt. *J. Dairy Sci*., 59, 344, 1975.
15. Benezech, T. and Maingonnat, J.F. Characterization of the rheological properties of yoghurt—A review. *J. Food Eng*., 21, 447, 1994.
16. Szczesnaik, A.S. Texture: It is still an overlooked food attribute? *Food Technol*., 44(9), 86, 1990.
17. Borwankar, R.P. Food texture and rheology: A tutorial review. *J. Food Eng*., 16, 1, 1992.
18. Friedman, H.H., Whitney, J.E., and Szczesnaik, A.S. The texturometer—A new instrument for objective texture measurement. *J. Food Sci*., 28, 390, 1963.
19. Szczesnaik, A.S. Texture profile analysis—Methodology interpretation clarified. *J. Food Sci*., 60(6), vii, 1995.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

20. Bourne, M.C. Method for obtaining compression and shear coefficients of foods using cylindrical punches. *J. Text. Stud*., 5, 459, 1975.
21. Masi, P. The collaborative compression tests on cheeses, in Jowitt, R., Escher, F., Kent, M., McKenna, B., and Roques, M. (eds.), *Physical Properties of Foods-2*. Elsevier Applied Science Publishing Co., London, U.K., 1987, pp. 383–401.
22. McKenna, B. Overall survey of the COSTbis work on the solid properties of foods, in Jowitt, R., Escher, F., Kent, M., McKenna, B., and Roques, M., (eds.), *Physical Properties of Foods-2*. Elsevier Applied Science Publishing Co., London, U.K., 1987, pp. 367–382.
23. Brennan, J., Jowitt, G.R., and Mugali, O.A. Some experiments with general foods texturometer. *J. Text. Stud*., 1, 167, 1970.
24. Emmons, D.B. et al. Milk gel structure X. Texture and microstructure in Cheddar cheese made from whole and homogenized low fat milk. *J. Text. Stud*., 11, 15, 1980.
25. Bryant, A., Ustunol, Z., and Steffe, J. Texture of Cheddar cheese as influenced by fat reduction. *J. Food Sci*., 60(6), 1216, 1995.
26. Bourne, M.C. *Food Texture and Viscosity: Concept and Measurement*, 2nd edn. Academic Press, San Diego, CA, 2002.
27. Viñas, M.A.G. et al. Relationship between sensory and instrumental measurements of texture for artisanal and industrial Manchego cheeses. *J. Sensory Stud*., 22, 462, 2007.
28. Brickley, C.A. et al. Influence of emulsifying salts on the textural properties of nonfat process cheese made from direct acid cheese bases. *J. Dairy Sci*., 91, 39, 2008.
29. Everard, C.D. et al. A three-point bending test for prediction of sensory texture in processed cheese. *J. Text. Stud*., 38, 438, 2007.
30. Farkye, N.Y. et al. Sensory and textural properties of Queso Blanco-type cheese influenced by acid type. *J. Dairy Sci*., 78, 1649, 1995.
31. DeMan, J.M. and Beers, A.M. Review: Fat crystal networks: Structure and rheological properties. *J. Text. Stud*., 18, 303, 1987.
32. Dioxn, B.D. Spreadability of butter: Determination. Description and comparison of five methods of testing. *Aust. J. Dairy Tech*., 29, 15, 1974.
33. Mickle, J.B., Von Gunten, R.L., and Morrison, R.D. Rearrangement of milk fat as a means for adjusting hardness of butterlike products. *J. Dairy Sci*., 46, 1357, 1963.
34. Bobe, G. et al. Texture of butter from cows with different milk fatty acid compositions. *J. Dairy Sci*., 86, 3122, 2003.
35. Muir, D.D. and Hunter, E.A. Sensory evaluation of fermented milks: Vocabulary development and the relations between acceptability and sensory properties. *J. Soc. Dairy Technol*., 45, 73, 1992.
36. Cobos, A., Horne, D.S., and Muir, D.D. Rheological properties of acid milk gels. 1. Effect of composition, process and acidification conditions on products from recombined milks. *Milchwissenschaft*, 50, 444, 1995.
37. Xiong, Y.L. and Kinsella, J.E. Influence of fat globule membrane composition and fat type on the rheological properties of milk based composite gels. I. Methodology. *Milchwissenschaft*, 46, 150, 1991.
38. Vlahopoulou, I. and Bell, A.E. Effect of various starter cultures on the viscoelastic properties of bovine and caprine yogurt gels. *J. Soc. Dairy Technol*., 46, 61, 1993.
39. Rhom, H. and Kovac, A. Effects on starter cultures on linear viscoelastic and physical properties of yogurt gels. *J. Text. Stud*., 25, 311, 1994.
40. Salvador, A. and Fiszman, S.M. Textural and sensory characteristics of whole and skimmed flavored set-type yogurt during long storage. *J. Dairy Sci*., 87, 4033, 2004.
41. Krasaekoopt, W., Bhandari, B., and Deeth, H. Comparison of texture of yogurt made from conventionally treated milk and UHT milk fortified with low heat skim milk powder. *J. Food Sci*., 69(6), E276, 2004.
42. Sandoval-Castilla, O. et al. Microstructure and texture of yogurt as influenced by fat replacers. *Int. Dairy J*., 14, 151, 2004.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

43. Mohamed, M.O. and Morris, H.A. Textural and microstructural properties of rennet-induced milk coagulum as affected by the addition of soy protein isolate. *J. Text. Stud*., 18, 137, 1987.
44. Ozer, B.H. et al. Comparison of techniques for measuring the rheological properties of labneh (concentrated yogurt), *Int. J. Dairy Technol*., 50(4), 129, 1997.
45. Gunasekaran, S. and Ak, M.M. *Cheese Rheology and Texture*. CRC Press, Washington DC, 2003.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 20

Rheological Properties and Flavor Release

Nathalie Cayot

Contents

20.1 Introduction 354
20.1.1 Textural Variety of Dairy Foods 354
20.1.2 Influence of Rheological Properties on Flavor Release 355
20.2 How to Characterize Flavor Release? 356
20.2.1 Mechanistic Approach to Flavor Release 356
20.2.2 Methods to Measure Diffusion 356
20.2.2.1 Nuclear Magnetic Resonance and Self-Diffusion 357
20.2.2.2 Concentration Profiles 357
20.2.2.3 Diffusion Cell 358
20.2.3 Methods to Measure Flavor Transfer 359
20.2.3.1 In Vitro or In Vivo Experiments 360
20.2.3.2 Static or Dynamic Headspace Measurements 360
20.3 Influence of Rheological Properties on Flavor Release from Dairy Foods 360
20.3.1 Gel Model Systems 360
20.3.2 Yoghurts 361
20.3.3 Custard 363
20.3.4 Cheese 363
20.4 Conclusion 364
References 366

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

20.1 Introduction

Flavor is one of the key factors determining food quality and acceptance. When formulating food products, it is thus important to be able to control flavoring during processing, storage, and consumption. Since the release of aroma compounds is widely assumed to be responsible for the characteristic flavor of food, many works focus on the release of volatile constituents. Aroma compounds present in a food product are distributed between the matrix and the gas phase. Then, a fraction of the free flavor can reach the olfactory receptors and the food consumer can perceive the aroma.

Food texture may be of concern at different levels but is a main concern during food consumption. In fact, the way to handle food depends a lot on its texture: beyond interindividual differences, liquid products are swallowed more rapidly than solid products. The strength applied by teeth to bite food products and to transform the food bolus depends a lot on food stiffness. When food is eaten, it undergoes many modifications due to mastication, but also dilution through the addition of saliva, and variation in temperature. These modifications result in great changes in food structure and texture, and thus involve significant changes in the partition of aroma compounds between the matrix and the air phase [1].

20.1.1 Textural Variety of Dairy Foods

The dairy industry is one of the most highly developed food industries in the world. In fact, as a major source of protein, milk was used from the very beginning of humanity when prehistoric man became a stock breeder. Together with the development of the food industry, many industrial dairy products appeared, thanks to processes such as thermal treatments (UHT), protein fractionation (isolation, purification), and protein modification (enzymes, microorganisms).

All the resulting by-products or intermediate products were thus involved in food formulations to design new foods, new textures, new functionalities, and new services.

The functional properties of milk proteins are diverse: mainly, gelling properties, emulsifying properties, and foaming properties. Within the range of dairy products, these properties are used to produce:

- Gels with a wide range of hardness and mesostructure depending on the mechanism involved in gel setting (thermal gelation, coagulation by acidification, or by enzymatic action) and depending on the ripening (from yoghurts to cheeses).
- Emulsions and foams, such as ice creams.

The addition of polysaccharides may lead to semiliquid to semisolid dairy desserts.

Dairy products could also be multiphasic products or multilayer products.

Flavor perception is governed by the way aroma molecules are distributed through various phases [2]. In multilayer products, for example, containing dairy products and fruit preparations, transfers of colorings, sugar, water, protons, and flavor occur simultaneously between the different layers due to concentration gradients and can modify the sensory properties of the product [3].

The texture and rheological characteristics of such products are linked to their mesostructure, i.e., aggregation of casein micelles, thermodynamic incompatibility between polysaccharides, granulometry of particles, or size of fat globules.

For example, creaminess, one important property of texture for semisolid dairy desserts, can be increased by

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

- Increasing the bulk-viscosity of the food.
- Minimizing, but not eliminating, loss of bulk-viscosity during oral processing by using starches that show limited mechanical and enzymatic break down during oral processing.
- Using small stable fat droplets.
- Adding flavors associated with creaminess [4].

Others [5] found that fat-free, stirred yoghurts could be perceived more or less creamy depending on the viscosity, as for semisolid dairy desserts, and on the particle size: products perceived as creamy were firm; however, when particle size was above 150 mm, products could not be perceived as creamy.

20.1.2 Influence of Rheological Properties on Flavor Release

Many studies, done in a static state, i.e., in a state of equilibrium between the matrix and the gaseous phase, showed that the chemical nature of the different constituents involved in the product and their state have an impact on aroma partition [6]. For example, Relkin et al. [7] reported studies with flavored food emulsions containing either hydrogenated palm kernel oil or anhydrous milk fat. The fats differed by their fatty acid and triacylglycerol compositions and by their melting behavior, while the aroma compounds (ethyl butanoate, ethyl hexanoate, methyl hexanoate, mesifurane, linalool, diacetyl, *cis*-3-hexen-1-ol, and gamma-octalactone) differed by their hydrophobicity. Differential scanning calorimetry measurements applied to fat samples in bulk and emulsified forms indicated differences in the ratio of solid-to-liquid between temperatures ranging from 10°C to 35°C. Solid-phase microextraction (SPME) coupled with GC–MS analysis indicated that flavor release from food emulsions containing animal or vegetable fat differed depending on both the nature of the fat and the hydrophobicity of the flavor compound.

Additionally, other authors demonstrated that aroma transfer through the different phases may be influenced by the structure of the matrix. For example, Seuvre et al. [8] studied the retention of some aroma compounds in a medium based on water and miglyol. This mixture was emulsified with β-lactoglobulin or used as it is. Among the studied aroma compounds, 2-nonanone, and isoamyl acetate present opposite behaviors: the volatility of isoamyl acetate was not affected by the change of the medium structure, whereas the volatility of 2-nonanone increased. The authors attributed the decrease of retention of 2-nonanone in the emulsified system to a modification in the fixation site for this compound on the protein or to competition between the lipid and the aroma compound, while the protein was adsorbed at the lipid–water interface.

In viscous or solid matrices, diffusion of small molecules such as volatile compounds may be lowered. In fact, following the Stokes–Einstein law (Equation 20.1), the diffusion coefficient of a molecule in a given medium is inversely proportional to its viscosity:

$$D_i = \frac{kT}{6\pi\eta r} \tag{20.1}$$

with
k is the Boltzman constant
T is the temperature (K)
η is the dynamic viscosity (Pa s)
r is the radius of the molecule (m)

This was also observed in gelled products containing polysaccharides [9–14].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

During food consumption, mastication influences flavor perception due to the increase in surface exchange and the modification of the concentration gradient for the aroma compounds. During this step, the food product is distorted by teeth, tongue, and palate. Different types of distortion can be distinguished: shearing, stretching, and compression, fractionation. The main type of distortion will depend on the structure of the product: for a solid product, mainly compression and fractionation will occur, for a viscous product, shearing will be the main distortion observed [15].

Several *in vitro* studies showed that mastication led to an increase in aroma release [16,17]. Other authors [18] reported that the duration of mastication had an impact on the amount of released aroma, depending on the polarity of the aroma compound.

Considering all these studies, it appears that aroma release and its evolution with rheological properties is a complex phenomenon. Both macroscopic and microscopic scales must be considered to fully understand the rheological properties of the food matrix as well as the partition of aroma compounds. More than that, static and dynamic measurements are needed to fully understand the mechanisms of aroma release. Methods are being explored in order to make measurements at different scales and to make it possible to handle texture variation and flavor release simultaneously.

20.2 How to Characterize Flavor Release?

20.2.1 Mechanistic Approach to Flavor Release

As discussed above, the measurement of transport phenomena is a central preoccupation when trying to explain aroma perception.

In food products, transfers of small molecules can occur between two phases of the product that are heterogeneous in terms of composition or in terms of physical state (liquid, solid, or gaseous). To measure these transfers, diffusion coefficients (D) are needed. However, it is not always easy to determine such dynamic parameters [19]. Many methods exist but they are not always suitable for the measurement of transport phenomena of volatiles [20].

Two main mechanisms of mass transfer can be considered in such cases: convective transport in well-stirred phases and diffusive transport in motionless phases.

Diffusion is the process by which matter is transported from one part of a system to another [21]. The rate of transfer of one component across a fixed-volume section may be expressed as the combined effect of mass flow, proportional to the concentration gradient normal to the section, and true diffusion, resulting from random molecular motions [22]. Molecular diffusion can be explained by the free volume concept [23] and also depends on medium viscosity, as expressed by Stokes–Einstein relations that distinguish translational and rotational diffusions. Translational diffusion, expressed in $m^2\ s^{-1}$, corresponds to the diffusion of molecules as a function of their concentration gradient. Rotational diffusion, expressed in s^{-1}, corresponds to the frequency of molecular reorientation.

Experimentally, while determining diffusion coefficients in a complex medium, the term apparent or effective diffusion is generally preferred because not only molecular diffusion is taken into account but also other phenomena, which cannot be distinguished from molecular diffusion, such as capillary or Knudsen diffusion, as well as diffusion modification due to matrix changes (obstruction, retraction…) are taken into account.

20.2.2 Methods to Measure Diffusion

There is no standardized method to determine the diffusivity of small molecules in food systems. Pure or true diffusion based on Fick's law rarely occurs alone as foods are complex systems with

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

different phases (gas, liquid, gel, solid), each of them being characterized by different transport properties. Effective or apparent diffusivity is generally measured for these complex systems.

Instrumental techniques such as nuclear magnetic resonance (NMR) spectroscopy are high-resolution tools for diffusion measurements in homogeneous media, but mobility can also be characterized by experimental methods based on the presence of a concentration gradient [24]. Some methods that have been used to determine diffusivity of aroma compounds within solid or semisolid (such as gels) food products are reported hereafter.

20.2.2.1 Nuclear Magnetic Resonance and Self-Diffusion

By using radioactively labeled molecules, it is possible to determine the rate of diffusion of one component in a two-component system of uniform chemical composition. What is involved is an interchange of labeled and unlabeled molecules while the total amount of that molecule, labeled and unlabeled, is constant throughout the system. As a consequence, no mass-flow occurs and what is measured is a self-diffusion coefficient [21].

The NMR spectroscopic technique using the pulsed field gradient (PFG) spin-echo method is a nondestructive and noninvasive way to measure the self-diffusion coefficient of small molecules through the detection of their protons' mobility, but only for values over $10^{-14}\,m^2\,s^{-1}$ [25]. This method is thus perfectly suitable for high-water content media, such as water or aroma compounds in gels [26]. Likewise, the PFG-diffusion ordered spectroscopy (DOSY) technique also gives self-diffusion coefficients through the identification of protons assigned to a given molecule, as for aroma compounds in sucrose-based solutions or a carrageenan matrix [12,27].

In the study of Savary et al. [27], cross-linked waxy corn starch and carrageenans in combination with sucrose were used to mimic the structure of fruit preparation models. DOSY-PGF-NMR spectroscopy was used to measure self-diffusion coefficients of aroma molecules in the model fruit preparations. The authors reported that this method was convenient and accurate. It allowed them to show that, in the studied systems, the decrease in the self-diffusion of aroma molecules was principally dependent on the sucrose content. As a consequence, self-diffusion decreased as medium viscosity increased.

20.2.2.2 Concentration Profiles

At a microscopic scale, the concentration–distance curves—or concentration profiles—method consists of bringing into contact two cylinders of a solid or semisolid product, either of which contains a different initial concentration of the studied substance. The concentration profiles are measured from their distance to the interface, as a function of time, along a one-dimension axis. However, this type of experiment is generally destructive. Thin slicing of the sample gives a spatial resolution of about 1 mm. It was used by different authors [3,28–30].

Recently, Nongonierma et al. [3] used such a method to study the transfer of colorants in a multiphasic stirred fruit yoghurt model. This yoghurt model was made of a pectin gel aimed to mimic fruit pieces and a dairy gel made with milk acidified by glucono-δ-lactone hydrolysis. To measure transfers, the gels were put in glass tubes of 200 mm length and 5 mm internal diameter half filled with the pectin gel and the other half with the dairy gel. The tubes were closed with septa. Transfer of colorants was determined by measuring the optical density in the biphasic samples, at different storage times. The optical density was measured every 0.8 mm in each gel.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Diffusivity of the colorant was determined using Fick's second law, assuming that

- At $T = 0$, there was no colorant in the noncolored gel (pectin gel)
- The concentration of colorant in the colored gel (dairy gel) was constant
- During the transfer, there was a local equilibrium at the interface between the two gels
- There was no accumulation of colorant at the interface

Thanks to this method, the authors found that the diffusivity in the two gels depended not only on the molar mass of the colorants, but also on their charge. In the pectin gel, the diffusivity of negatively charged colorants was the lowest. The authors hypothesized that charged colorants might interact with the constituents of the pectin gel. In the dairy gel, migration of colorants was affected by hydrophobic and electrostatic interactions with the components of the gel (i.e., proteins and fat).

20.2.2.3 Diffusion Cell

With the diaphragm cell technique, two compartments (with different initial solute concentrations) are separated by the product in which the diffusivity has to be measured [31]. As the solute diffuses through the product, concentrations in both compartments are measured as a function of time, and the diffusion coefficient is determined on the basis of Fick's second law.

On this basis, a rotating diffusion cell was developed to investigate the rate of transfer of solutes from an aqueous phase to another phase through a lipid layer, as a model of double emulsions, along with the resistances to mass transfer within the aqueous boundary layers, across the oil–water interface and within the oil layer. The rotating diffusion cell (Figure 20.1a) was designed hydrodynamically in such a way that stationary diffusion layers of known thickness were created on each side of the oil layer [32].

Landy et al. [32] used this device to study the transfer of solutes (ethyl acetate, ethyl butanoate, and ethyl hexanoate) from aqueous phases to oil (miglyol), and from oil to aqueous phases

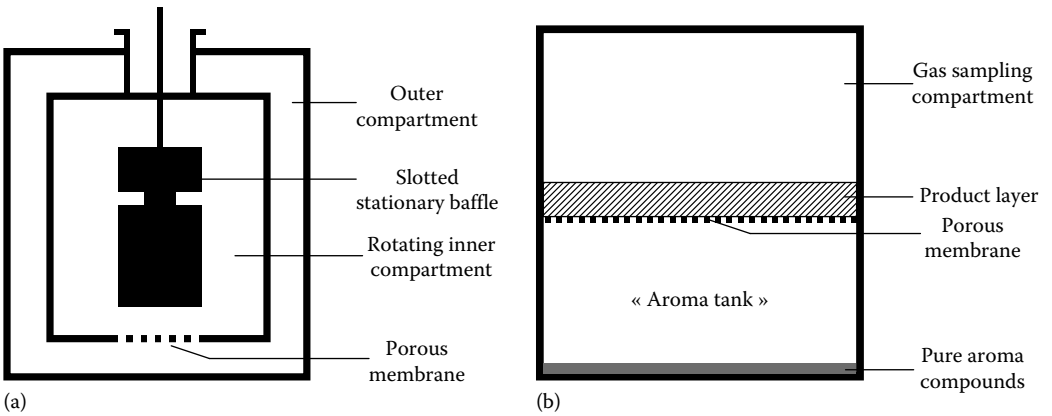


Figure 20.1 Schematic representation of different diffusion cells used to measure diffusion of aroma compounds. (a) Rotating diffusion cell. (Adapted from Landy, P. et al., *Colloids Surf. B: Biointerfaces*, 12(1), 57, 1998.) (b) Diffusion cell. (Adapted from Déléris, I. et al., *J. Food Eng.*, 85(2), 232, 2008. With permission.)

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

by determining resistances to mass transfer of the solute and by estimating the rate-limiting step of the transfer. They found that the transfer of ethyl acetate through the interface was the rate-limiting step, while the transfer of ethyl butanoate and ethyl hexanoate through the oil was limited by the diffusion in the aqueous phase. The effect of sodium caseinate was different for the less hydrophobic compound (ethyl acetate) and the more hydrophobic compounds (ethyl butanoate and ethyl hexanoate); in the presence of sodium caseinate, the R_{aq} value (resistance to diffusion through the two stagnant aqueous diffusion layers which are established at each side of the filter) increased for ethyl acetate, while the R_I value (resistance due to the solute transfer across the two aqueous phase/oil interfaces) increased for ethyl butanoate and ethyl hexanoate.

Déléris et al. [24] developed another experimental device, based on the diffusion cell concept, to determine the apparent diffusivity of aroma compounds within food products using direct gaseous measurements.

In their device, two main gaseous compartments were separated by the food product being studied, which was supported by a thin hydrophobic porous membrane. The "aroma tank" (Figure 20.1b) contained a small volume of pure aroma compounds and ensured a constant gaseous concentration throughout the whole experiment. Aroma compounds moved from the lower compartment, passed through the gas phase contained within the membrane pores, diffused through the food product, and were finally released into the gaseous phase of the sampling compartment.

They compared the diffusion results they obtained using this device with data found in the literature for simple model systems and concluded that their system was reliable and robust. Then, they used this diffusion cell to measure apparent diffusion coefficients of ethyl hexanoate and ethyl acetate in a stirred yoghurt enriched with caseinates. They found that the yoghurt had a clear impact on the diffusion properties of both compounds: the presence of yoghurt decreased diffusion compared with that measured within 1% agar gel. Depending on the physicochemical properties of aroma compounds, the effect was much more pronounced for ethyl hexanoate (36-fold decrease) than for ethyl acetate (2.4-fold reduction).

20.2.3 Methods to Measure Flavor Transfer

Numerous methods have been developed to monitor variations in aroma concentration in the gas phase as a function of time. The development by Lee [33] of a system, which was able to monitor the headspace continuously by using a mass spectrometer coupled with a dynamic headspace system, was followed by many other attempts to follow and/or reproduce the oral processing of food.

When the purpose is to follow aroma release during the consumption of a food product, the measurement can be done directly during consumption of the food product thanks to *in vivo* measurement as is the case for the API-MS "in nose" method or the "in mouth" method as developed by Taylor and Linforth [34]. Sensory analysis and *in vivo* aroma delivery were carried out in low-fat and regular-fat milk samples prepared with the same amount of ethyl hexanoate [35]. The sensory results were in accordance with differences in aroma delivery, with low-fat samples delivering more ethyl hexanoate than regular-fat samples. Aroma content in low-fat samples was adjusted so that aroma delivery *in vivo* was the same for both low-fat and regular-fat samples. In this case, panelists could not differentiate between samples, which showed a good correlation between aroma delivery and perception. In this case, concerning a liquid product with a major and well-known effect of fat, the sensory method and *in vivo* aroma measurement were in accordance, which is not always the case for other products.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Some devices can also be used to mimic phenomena occurring during food consumption (*in vitro* measurement). Van Ruth and Roozen [36] developed a model system in which mouth conditions are simulated taking into account the volume of the mouth, temperature, salivation, and mastication. Different laboratories are developing more and more complex "artificial mouth" systems, which are able to handle food products of different textures. Such a device is being designed by Mielle et al. [37] with the objective to reproduce as closely as possible the destructuration of food as done by teeth and by the compression between tongue and palate.

Depending on the aim of the study, on the timescale for observations, and on the methods available, experiments can be conducted by discrete or by continuous sampling of the headspace. For the qualitative and quantitative analyses of volatile compounds, gas chromatography is of course the reference technique.

The release of volatile compounds may be influenced by numerous parameters such as temperature, structure or texture, pressure, relative humidity, dilution by saliva, enzymatic reactions, respiratory flux, and chewing pattern. The control of all these parameters is of major importance for the reproducibility of measurements and comparisons of data sets.

20.2.3.1 In Vitro or In Vivo Experiments

Concerning *in vivo* measurements, the flavored food product is placed in the mouth and flavor release in the oral or nasal cavity is analyzed, whereas for *in vitro* measurements the product is placed in a container and the analysis concerns aroma compounds released in the headspace.

In both cases, several forms of sampling and detection can be used. Most of the time, direct analysis is used for *in vivo* measurements with proton-transfer reaction mass spectrometry (PTR-MS) or atmospheric pressure chemical ionization mass spectrometry (APCI-MS). In this case, chemical ionization allows quantitative analysis of aroma release on line [38]. For *in vitro* measurements, sampling of the gaseous phase was more often done by discrete sampling with a gas syringe, an SPME fiber or *via* a trap on an adsorbent polymer.

20.2.3.2 Static or Dynamic Headspace Measurements

For *in vitro* measurements, the analysis of the headspace can be done using static or dynamic measurements. In static measurements, the gas phase is sampled at thermodynamic equilibrium and the system is closed, whereas in dynamic measurements equilibrium is not reached and the system is open. The method of exponential dilution consists in studying the exponential decrease in the concentration of aroma compounds in the gas phase with time after reaching equilibrium [39,40]. Other authors considered an initial state near zero and followed the release of aroma compounds in the headspace with time until reaching equilibrium [41].

20.3 Influence of Rheological Properties on Flavor Release from Dairy Foods

20.3.1 Gel Model Systems

Gel model systems have often been used to study interactions between specific compounds of dairy products and aroma compounds or even to follow transfers and other transport phenomena. Gel models based on biopolymers are convenient models to study the impact of texture on aroma

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

release, as their rheological properties can be easily modified by varying biopolymers in concentration or in nature. Nevertheless, the consequence of such an approach is that it is sometimes difficult to separate the impact of physicochemical interactions from the impact of texture on aroma release, and it is risky to show a general trend.

In gel model systems, different authors [42,43] observed that aroma release decreased when the rigidity of gels increased. However, Weel et al. [44] and Mestres et al. [45] showed that the quantity of aroma released was not modified by the texture of whey protein gels. Other studies showed an increase in the amount of aroma released with increased hardness of gelatin and pectin gels [13].

In a recent study, Monge et al. [46] used pectin gels at different polymer concentrations as matrices for the encapsulation of a volatile flavor (limonene). They aimed to study the influence of the viscoelastic properties of the matrix on flavor release toward the gel headspace. The electronic nose technique and principal component analysis were used to detect changes in the fingerprint of the released vapor as a function of pectin concentration. Samples with different compositions were also studied by rheological measurements in order to distinguish between the effects of polymer concentration on gelation kinetics and those due to the addition of limonene and the detergent used to dissolve it.

They obtained a correlation between the decrease in flavor release intensity and the increase in solid-like character of the matrix. Comparing the viscoelastic properties of matrices with and without the flavor, with direct observations by optical microscopy, the authors concluded that the release modulation was mainly due to the interaction of the gelling pectin with the microemulsion of detergent and flavor.

The release of a strawberry aroma from different composite gels taken as models of fruit preparations and from a sucrose solution was investigated by Savary et al. [47]. The composition of the model systems differed with regard to the gelling agent, either pectin or carrageenan, and to the rigidity of the gel. The release profiles of the aroma compounds were determined under stirring by APCI-MS. At the same time, purge and trap measurements were performed to determine the release profiles of the aroma compounds without stirring. The authors aimed to determine how the structure of the matrix, the mechanical treatment and the properties of the aroma compound affect aroma release. In purge and trap measurements, the gelled systems were not sheared and the structure of these unsheared gelled matrices played a role in the release of ethyl hexanoate; in the case of the carrageenan-based composite systems, increasing the amount of carrageenan induced a decrease in the release of ethyl hexanoate. APCI-MS experiments showed clearly that an increase in the release of ethyl hexanoate was triggered as soon as stirring was applied:

- The more gelled the matrix, the faster the release.
- The higher the initial rigidity of the gel, the greater the degree of break down and the greater the amount of aroma compound released from the matrix.

The results with the sucrose solution showed a higher release of aroma compounds as compared to the release from gels that was attributed to a higher diffusion coefficient. In fact, Savary et al. [27] measured this parameter by NMR–DOSY and found that for ethyl butyrate, release from the gel was about 50% lower than that from the sucrose solution.

20.3.2 Yoghurts

In the field of dairy products, yoghurts of different types were a main concern.

To study aroma release from stirred yoghurt during storage, Decourcelle et al. [48] used a blend of five aroma compounds in food concentrations. Thickeners were incorporated into

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

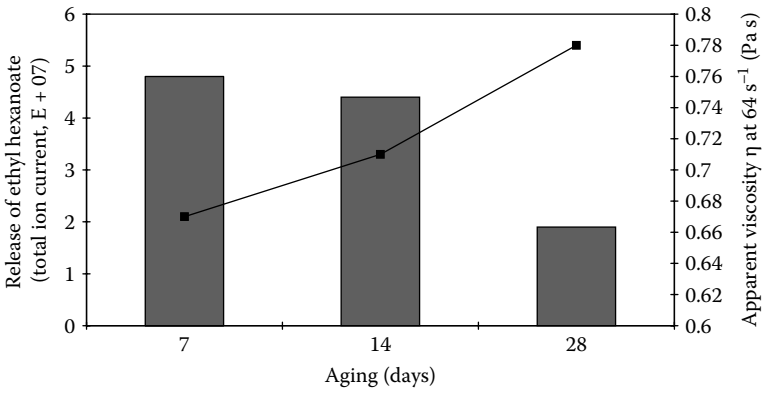


Figure 20.2 Release of ethyl hexanoate and apparent viscosity for fat-free stirred yoghurt during storage. Aroma release was followed by SPME. Apparent viscosity was measured in a coaxial cylinder viscometer at 64 s^{-1}. Both measurements were conducted at 21°C. (Adapted from Decourcelle, N. et al., *Int. Dairy J.*, 4(9), 783, 2004.)

industrial yoghurt via a model fruit preparation. Flavor release from the yoghurt was determined using a SPME method. Rheological characterization was performed to try to link the release of the aroma compound and the macroscopic properties of yoghurt. Flavor release and rheological properties of the product were followed during a 28 days storage period. The apparent viscosity (η) at a shear rate of 64 s^{-1} was obtained with a coaxial cylinder viscometer at 21°C. No significant difference was noted between the first two samples (7 and 14 days). At the third period of aging, the quantity of flavors in the headspace of yoghurts was significantly lower for methyl 2-methylbutanoate, ethyl hexanoate, and hexyl acetate. The quantity was half in comparison with that in day 7 (Figure 20.2). The authors underlined that, putting aside the presence of proteins and polysaccharides, which can interact with aroma compounds; the rheological characteristics of yoghurt change during aging. The main effect they observed on a plain yoghurt was an increase in viscosity due to bacterial activity, which decreased the pH during aging. Indeed, the strength of the protein network increased along with the increase in the amount of lactic acid and exopolysaccharide production, from live bacteria in yoghurt. They thus concluded that the changes in rheological properties observed during aging could partly explain the results in flavor release.

Nongonierma et al. [49] followed the release of strawberry flavor compounds at vapor/matrix interfaces in model food systems simulating a yoghurt with a fruit preparation syrup. The effect of different parameters including the physicochemical characteristics of the flavor compound, the structure, and composition of the matrix and the temperature on the release of the flavor compounds were investigated. There was an effect of the composition and structure of the matrix upon the partition of the flavor compounds. In the dairy gel, retention of flavor compounds was caused by the physicochemical interactions with the proteins and the solubilization in dispersed fat. The addition of syrup to the low-fat dairy gel slightly increased the retention of the flavor compounds; this was attributed to physicochemical interactions with pectin and sucrose. In the presence of fat (5%), the flavor compounds were solubilized in the fat and their release was not affected by the composition of the dispersing medium. As expected, temperature affected the release; an increase from 4°C to 10°C resulted in an increase in the overall amount of flavor released. This work is in accordance with the numerous studies that demonstrate the preponderant effect of fat on the flavor release from model yoghurts. In the low-fat dairy gels used by the authors, the addition

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

of thickeners such as pectin contained in the syrup was not sufficient to control the release. Nongonierma et al. [49] suggested that the structure of the residual fat globules of skimmed milk could be modified in order to improve the sensory quality of low-fat yoghurts.

20.3.3 Custard

De Wijk et al. [50] studied the effect of milk fat content (0%–15%) in vanilla custards with different starch types and concentrations by means of sensory and instrumental tests such as image analysis, turbidity, friction, and rheological measurements. They found great differences in the texture attributes perceived in these systems due to the different fat contents used. Tárrega and Costell [51] observed important differences in the pasting behavior, viscoelastic parameters, and the in-mouth thickness perceived when studying skimmed and whole milk dairy desserts containing λ-carrageenan. A work of Gonzalez-Tomas et al. [52] dealt with the influence of the type of milk (whole or skimmed) on the flow behavior, flavor release, and perception of strawberry-flavored custard model systems. The type of milk was observed to influence flavor release and sensory perception of strawberry flavor.

Lethuaut et al. [53] observed differences in the perceived texture of dairy desserts formulated with skimmed milk, two levels of sucrose and three types of carrageenan. In a later work, Lethuaut et al. [54] studied the *in vivo* release by MS-nose and sensory perception of flavor by time–intensity measurements with the same samples. Changes in sweetness and aroma perception were observed, while aroma release remained unaffected, suggesting that perceptual interactions between aroma, sweetness, and texture occurred.

In a recent work, Gonzalez-Tomas et al. [55] studied aroma release by APCI-MS in low-fat dairy desserts. Four formulations were prepared with different starch concentrations, with or without κ-carrageenan. The amounts of sugar, strawberry flavor, and the weight of rehydrated skimmed milk remained fixed. Ten panelists were asked to breathe in, sip 5 mL of sample, close their mouths, swallow the sample then exhale, and continue to breathe normally while resting their nose on the APCI-MS nasal sampling tube. The data were analyzed to extract two parameters, the maximum aroma intensity (I_{max}) and the cumulative area under the 1 min release profile (A_{cum}). The rheological properties of the low-fat desserts were significantly affected by both starch and κ-carrageenan content, leading to significant differences in the orally perceived thickness. In spite of these differences, neither flavor release nor the perception of strawberry flavor intensity of the low-fat dairy dessert was significantly affected (Figure 20.3).

Kersiene et al. [56] studied the same type of products, measuring flavor release of custard desserts by headspace SPME. The authors also concluded that the presence of milk fat induced a significant decrease in the headspace concentration of flavor compounds. An elevated starch concentration enhanced the strength of the custard gels considerably. During storage time, a denser network was formed as shown by rheological measurements, but no significant difference in flavor release was noted upon storage (3 days).

20.3.4 Cheese

Gierczynski et al. [57] observed an increase in the amount of aroma release with an increased hardness of model cheeses.

Tarrega et al. [58] studied the effect of cheese characteristics on both chewing behavior and aroma release. For this purpose, they followed the release of four aroma compounds during the

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

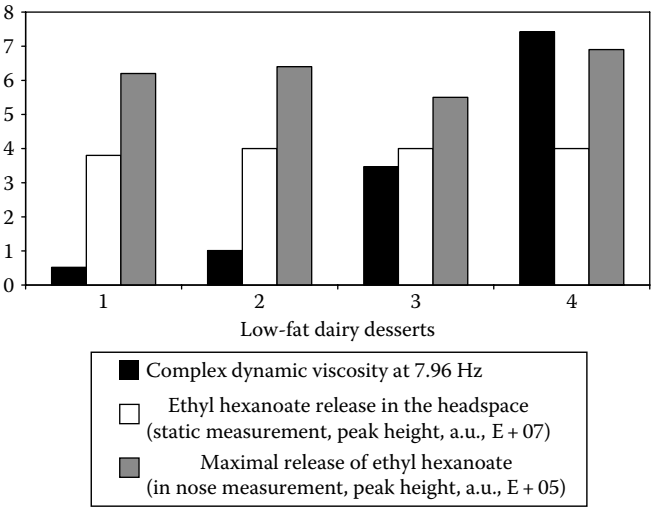


Figure 20.3 Dynamic complex viscosity and release of ethyl hexanoate for various models of low-fat dairy desserts storage. Rheological measurements were carried out in a controlled stress rheometer using parallel plate geometry at 10°C. Static headspace measurements were done by sampling the headspaces in turn into the APCI-MS at 5 mL min^{-1}. For *in vivo* aroma release, 10 panelists were asked to breathe in, sip 5 mL of sample, close their mouths, swallow the sample then exhale and continue to breathe normally, while resting their nose on the APCI-MS nasal sampling tube. Air from the nose was sampled into the APCI-MS source at 40 mL min^{-1}. (Adapted from Gonzalez-Tomas, L. et al., *Food Res. Int.*, 40(4), 520, 2007.)

consumption of eight equally flavored model cheeses. Cheese analogs of significantly different hardness were manufactured. They varied in the lipid–protein ratio, the type of fat, and the mixing speed during processing. The hardness of the cheese was determined with a TA-XT2 Texture Analyser at 10°C using a cylindrical probe of 5 mm diameter. The force required to penetrate the sample to a depth of 5 mm at a speed of 1 mm s^{-1} was recorded as the hardness value (N). The kinetics of aroma release and the chewing activity were simultaneously monitored during the consumption of cheese cubes by five subjects. Aroma release in breath was measured using API-MS. Value of the maximum concentration reached (I_{max}) was recorded on aroma release profiles obtained for each compound, product, and subject. Data obtained for 2-heptanone is shown in Figure 20.4. Tarrega et al. [58] analyzed their data through PLS regression applied to, on the one hand, the chewing parameters, cheese variables, and cheese hardness, and on the other hand, aroma release parameters. They concluded that the increase in hardness led to a considerable increase in chewing activity. In this case, the negative effect the structure had on aroma release can be counteracted and even inversed. Thanks to this study, they highlighted the strong interaction between cheese composition and chewing behavior on aroma release during cheese consumption. The composition influenced the texture of the product, which in turn influenced the chewing pattern and both influenced aroma release.

20.4 Conclusion

From the results reported above, it appears that many methodological problems are still to be solved in order to study the impact of texture on flavor release.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

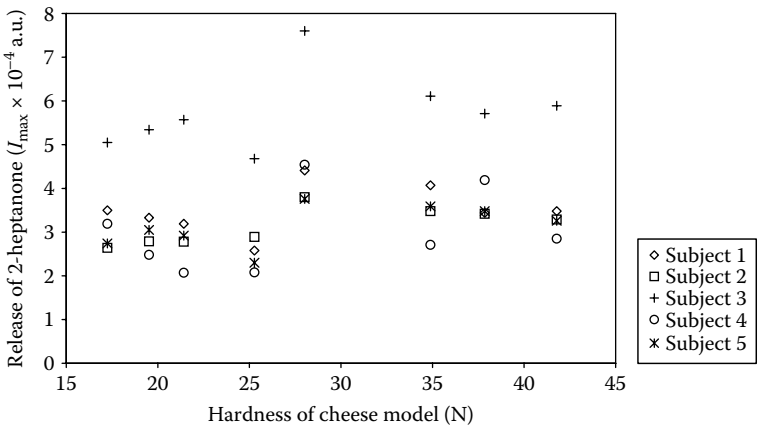


Figure 20.4 ***In vivo*** **aroma release from various model cheeses as a function of their hardness. Rheological measurements were carried out by penetrometry with a TA-XT2 at 10°C. Aroma release was monitored during the consumption of cheese cubes (7 g, 10°C) by five subjects. Subjects were asked to introduce the cheese cube in the mouth and to chew without swallowing. After completing 20 chewing cycles, they were allowed to swallow when they wanted. Aroma release in breath was measured using API-MS. Air from the nose was sampled at a flow rate of 35 mL min^{-1}. I_{max} is the maximum released intensity. (Adapted from Tarrega, A. et al.,** ***Int. Dairy J.,*** **18, 849, 2008.)**

- Firstly, there are numerous types of transfer and other transport phenomena, but they are often studied separately. Progress needs to be made in the measurement of at least coupled transfer analysis.
- Another difficulty is to handle the evolution of texture and aroma release simultaneously. Continuous sampling of aroma release can be achieved *in vivo* by APCI-MS, but the continuous measurement of the evolution of the rheological characteristics of a food bolus is not possible. In "mouth simulator" devices, it is often possible to measure viscosity and aroma release together continuously. Other devices are to be developed for solid products or to permit more sophisticated rheological measurements.
- Finally, the link between aroma release and aroma perception is still not well established. Among all interindividual differences that may explain the gap between aroma release and aroma perception, some authors stressed the impact of panelists' chewing patterns on the measurements. Other explanations also concern interaction among senses.

Nevertheless, assuming all the biases in the cited methodologies are solved, all the reported studies suggest that, in most cases, physicochemical interactions have a greater impact on aroma release than does texture. The effect of fat in particular has been extensively demonstrated. In addition to the cited examples, studies have also been conducted on ice creams. Li et al. [59] and Frøst et al. [60] found differences between ice-cream samples with different fat levels, both in terms of flavor and textural properties. Miettinen et al. [61] also reported that the amount of fat-affected aroma release when studying strawberry flavor ice creams with an electronic nose, sensory tests, and gas chromatography.

Nevertheless, in low-fat products, texture is a major factor in the control of aroma release.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

References

1. Taylor, A.J. et al., In vivo measurement of flavour release from mixed phase gels. *Biomol. Eng.*, 17(4–5): 143–150, 2001.
2. Bruin, S., Phase equilibria for food product and process design. *Fluid Phase Equilibr.*, 158–160: 657–671, 1999.
3. Nongonierma, A.B. et al., Transfers of small analytes in a multiphasic stirred fruit yoghurt model. *Food Hydrocol.*, 21(2): 287–296, 2007.
4. de Wijk, R.A. et al., Perceived creaminess of semi-solid foods. *Trends Food Sci. Technol.*, 17(8): 412–422, 2006.
5. Cayot, P. et al., Creaminess in relation to consistency and particle size in stirred fat-free yogurt. *Int. Dairy J.*, 18(3): 303–311, 2008.
6. Guichard, E., Interactions between flavor compounds and food ingredients and their influence on flavor perception. *Food Rev. Int.*, 18(1): 49–70, 2002.
7. Relkin, P., M. Fabre, and E. Guichard, Effect of fat nature and aroma compound hydrophobicity on flavor release from complex food emulsions. *J. Agric. Food Chem.*, 52(20): 6257–6263, 2004.
8. Seuvre, A.M., M.A. Espinosa Diaz, and A. Voilley, Influence of the food matrix structure on the retention of aroma compounds. *J. Agric. Food Chem.*, 48(9): 4296–4300, 2000.
9. Rega, B., E. Guichard, and A. Voilley, Flavour release from pectin gels: Effects of texture, molecular interactions and aroma compounds diffusion. *Sci. Aliments*, 22: 235–248, 2002.
10. Lubbers, S. and E. Guichard, The effects of sugars and pectin on flavour release from a fruit pastille model system. *Food Chem.*, 81(2): 269–273, 2003.
11. Bylaite, E. et al., Influence of lambda-carrageenan on the release of systematic series of volatile flavor compounds from viscous food model systems. *J. Agric. Food Chem.*, 52(11): 3542–3549, 2004.
12. Gostan, T. et al., Measurement of aroma compound self-diffusion in food models by DOSY. *Magn. Reson. Chem.*, 42(6): 496–499, 2004.
13. Boland, A.B., C.M. Delahunty, and S.M. van Ruth, Influence of the texture of gelatin gels and pectin gels on strawberry flavour release and perception. *Food Chem.*, 96(3): 452–460, 2006.
14. Juteau, A. et al., Flavour release from polysaccharide gels: Different approaches for the determination of kinetic parameters. *Trends Food Sci. Technol.*, 15(7–8): 394–402, 2004.
15. Overbosch, P., W.G.M. Afterof, and P.G.M. Haring, Flavor release in the mouth. *Food Rev. Int.*, 7(2): 137–184, 1991.
16. van Ruth, S.M. and J.P. Roozen, Influence of mastication and saliva on aroma release in a model mouth system. *Food Chem.*, 71(3): 339–345, 2000.
17. van Ruth, S.M. and K. Buhr, Influence of mastication rate on dynamic flavour release analysed by combined model mouth/proton transfer reaction-mass spectrometry. *Int. J. Mass Spectrom.*, 239(2–3): 187–192, 2004.
18. Buettner, A. and P. Schieberle, Influence of mastication on the concentrations of aroma volatiles—Some aspects of flavour release and flavour perception. *Food Chem.*, 71(3): 347–354, 2000.
19. Voilley, A. and I. Souchon, Flavour retention and release from the food matrix: An overview. In A. Voilley and P. Etievant (Eds.), *Flavour in Food*. Cambridge, U.K.: Woodhead Publishing Limited, 2006.
20. Cayot, N. et al., Measurement of transport phenomena of volatile compounds: A review. *Food Res. Int.*, 41(4): 349–362, 2008.
21. Crank, J. and G.S. Park, Methods of measurement. In J. Crank and G.S. Park (Eds.), *Diffusion in Polymers*. London: Academic Press Inc., 1968, pp. 1–39.
22. Crank, J., *The Mathematics of Diffusion*, 2nd edn. Oxford, U.K.: Oxford University Press, 1975.
23. Vrentas, C.M. and J.L. Duda, Diffusion of small molecules in amorphous polymers. *Macromolecules*, 9: 785–779, 1976.
24. Déléris, I. et al., An experimental device to determine the apparent diffusivities of aroma compounds. *J. Food Eng.*, 85(2): 232–242, 2008.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

25. Stilbs, P., Fourier transform pulsed-gradient spin-echo studies of molecular diffusion. *Prog. Nucl. Magn. Reson. Spectrosc*., 19(1): 1–45, 1987.
26. Rondeau-Mouro, C. et al., NMR investigations of the 4-ethyl guaicol self-diffusion in iota (iota)-carrageenan gels. *Carbohydr. Pol*., 57(4): 459–468, 2004.
27. Savary, G. et al., Influence of ingredients on the self-diffusion of aroma compounds in a model fruit preparation: An nuclear magnetic resonance-diffusion-ordered spectroscopy investigation. *J. Agric. Food Chem*., 54(3): 665–671, 2006.
28. Karathanos, V.T., A.E. Kostaropoulos, and G.D. Saravacos, Diffusion and equilibrium of water in dough/raisin mixtures. *J. Food Eng*., 25(1): 113–121, 1995.
29. Monnerat, S.M. et al., Concentration profiles and effective diffusion coefficients of sucrose and water in osmo-dehydrated apples. *Food Res. Int*., 39(6): 739–748, 2006.
30. Champion, D., H. Hervet, G. Blond, and D. Simatos, Comparison between two methods to measure translational diffusion of a small molecule at subzero temperature. *J. Agric. Food Chem*., 43: 2887–2891, 1995.
31. Cussler, E.L., *Diffusion: Mass Transfer in Fluid Systems* (Cambridge Series in Chemical Engineering), 2nd edn.. Cambridge, U.K.: Cambridge University Press, 1997.
32. Landy, P. et al., Thermodynamic and kinetic aspects of the transport of small molecules in dispersed systems. *Colloids Surf. B: Biointerfaces*, 12(1): 57–65, 1998.
33. Lee, W.E.I., A suggested instrumental technique for studying dynamic flavor release from food products. *J. Food Sci*., 51(1): 249–250, 1986.
34. Taylor, J.A. and R.S.T. Linforth, Methodology for measuring volatile profiles in the mouth and nose during eating, in *Trends in Flavour Research*, H. Maarse and D.G. van der Heij (Eds.). Amsterdam, the Netherlands: Elsevier Science, 1994, pp. 3–14.
35. Shojaei, Z.A., R.S.T. Linforth, and A.J. Taylor, Estimation of the oil water partition coefficient, experimental and theoretical approaches related to volatile behaviour in milk. *Food Chem*., 103(3): 689–694, 2007.
36. van Ruth, S.M. and J.P. Roozen, Gas chromatography/sniffing port analysis and sensory evaluation of commercially dried bell peppers (*Capsicum annuum*) after rehydration. *Food Chem*., 51(2): 165–170, 1994.
37. Mielle, P. et al., An "artificial mouth" as a novel sampling device for E-nose, E-tongue and API-MS, in *Proceedings of the 11th International Symposium Olfaction & Electronic Noses* (*ISOEN 05*), Barcelona, ESP, 2005.
38. Hansson, A., P. Giannouli, and S. Van Ruth, The influence of gel strength on aroma release from pectin gels in a model mouth and in vivo, monitored with proton-transfer-reaction mass spectrometry. *J. Agric. Food Chem*., 51(16): 4732–4740, 2003.
39. Langourieux, S. and J. Crouzet, Study of aroma compound–natural polymer interactions by dynamic coupled column liquid chromatography. *J. Chromatogr. A*, 707(2): 181–187, 1995.
40. Seuvre, A.M., M.A. Espinoza Diaz, and A. Voilley, Transfer of aroma compounds through the lipidic-aqueous interface in a complex system. *J. Agric. Food Chem*., 50: 1106–1110, 2002.
41. Juteau, A., J.L. Doublier, and E. Guichard, Flavor release from iota-carrageenan matrices: A kinetic approach. *J. Agric. Food Chem*., 52(6): 1621–1629, 2004.
42. Baek, I., et al., Sensory perception is related to the rate of change of volatile concentration in-nose during eating of model gels. *Chem. Senses*, 24(2): 155–160, 1999.
43. Guinard, J.X. and C. Marty, Time-intensity measurement of flavor release from a model gel system: Effect of gelling agent type and concentration. *J. Food Sci*., 60(4): 727–730, 1995.
44. Weel, K.G.C. et al., Flavor release and perception of flavored whey protein gels: Perception is determined by texture rather than by release. *J. Agric. Food Chem*., 50(18): 5149–5155, 2002.
45. Mestres, M. et al., Aroma release and retronasal perception during and after consumption of flavored whey protein gels with different textures. 1. In vivo release analysis. *J. Agric. Food Chem*., 53(2): 403–409, 2005.
46. Monge, E.M., et al., Correlation between rheological properties and limonene release in pectin gels using an electronic nose. *Food Hydrocol*., 22(5): 916–924, 2008.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

47. Savary, G., et al., Impact of destroying the structure of model gels on volatile release. *J. Agric. Food Chem*., 55(17): 7099–7106, 2007.
48. Decourcelle, N. et al., Effect of thickeners and sweeteners on the release of blended aroma compounds in fat-free stirred yoghurt during shear conditions. *Int. Dairy J*., 4(9): 783–789, 2004.
49. Nongonierma, A.B. et al., Flavour release at gas/matrix interfaces of stirred yoghurt models. *Int. Dairy J*., 16(2): 102–110, 2006.
50. de Wijk, R.A., J.F. Prinz, and A.M. Janssen, Explaining perceived oral texture of starch-based custard desserts from standard and novel instrumental tests. *Food Hydrocol*., 20(1): 24–34, 2006.
51. Tárrega, A. and E. Costell, Effect of composition on the rheological behaviour and sensory properties of semisolid dairy dessert. *Food Hydrocoll*., 20(6): 914–922, 2006.
52. Gonzalez-Tomas, L., et al., Flavour release and perception from model dairy custards. *Food Res. Int*., 40(4): 520–528, 2007.
53. Lethuaut, L. et al., Sweetness–texture interactions in model dairy desserts: Effect of sucrose concentration and the carrageenan type. *Int. Dairy J*., 13: 631–641, 2003.
54. Lethuaut, L. et al., Flavor perception and aroma release from model dairy desserts. *J. Agric. Food Chem*., 52(11): 3478–3485, 2004.
55. Gonzalez-Tomas, L. et al., Rheology, flavour release and perception of low-fat dairy desserts. *Int. Dairy J*., 18(8): 858–866, 2008.
56. Kersiene, M. et al., Interactions between flavour release and rheological properties in model custard desserts: Effect of starch concentration and milk fat. *Food Chem*., 108(4): 1183–1191, 2008.
57. Gierczynski, I. et al., Impact of hardness of model cheese on aroma release: In vivo and in-vitro study. *J. Agric. Food Chem*., 55(8): 3066–3073, 2007.
58. Tarrega, A. et al., Aroma release and chewing activity during eating different model cheeses. *Int. Dairy J*., 18(8): 849–857, 2008.
59. Li, Z. et al., Effect of milk fat content on flavor perception of vanilla ice cream. *J. Dairy Sci*., 80(12): 3133–3141, 1997.
60. Frøst, M.B. et al., Sensory measurement of dynamic flavour intensity in ice cream with different fat levels and flavourings. *Food Qual. Pref*., 16(4): 305–314, 2005.
61. Miettinen, S.M. et al., Electronic and human nose in the detection of aroma differences between strawberry ice cream of varying fat content. *J. Food Sci*., 67(1): 425–430, 2002.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 21

Flavor Formation

Barbara d'Acampora Zellner, Paola Dugo,
Giovanni Dugo, and Luigi Mondello

Contents

21.1 Brief Introduction to Dairy Flavor Formation 369
21.2 Flavor Formation in Milk 371
21.2.1 Milk Flavors Developed During Heat Treatment and Storage 371
21.2.2 Flavors Developed from the Autoxidation of Milk Lipids 372
21.2.3 Light-Induced Flavor Formation 373
21.2.4 Flavor Compounds Derived from Package Component Migration 373
21.3 Flavor Formation in Fermented Dairy Products: Cheese 374
21.3.1 Fermentation of Lactose and Conversion of Citrate 374
21.3.2 Proteolysis and Catabolism of Amino Acids 376
21.3.2.1 Metabolism of Branched-Chain Amino Acids 376
21.3.2.2 The Catabolism of Aromatic Amino Acids 377
21.3.2.3 Methionine and Its Catabolic Pathways 378
21.3.3 Lipolysis and Catabolism of Fatty Acids 378
21.4 Concluding Remarks 380
References 380

21.1 Brief Introduction to Dairy Flavor Formation

It is widely acknowledged that milk and its derived products are characterized by a heterogeneous nature, comprising significant levels of lipids, proteins, and carbohydrates. In this respect, the classification of flavor compounds based on their polarity or volatility turns out to be a difficult task. In addition, as is well known, the flavor composition varies according to the state of the dairy

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

sample, so that raw milk presents a distinct flavor when compared to that of heated or processed milk, with different classes of compounds responsible for the characteristic flavor of distinct samples. Generally esters are responsible for the flavor of raw milk samples, while lactones and heterocyclic compounds for that of heat-treated and pasteurized milk. On the other hand, fermented dairy products, such as cheese and yogurt, are characterized by the presence of fatty acids [1].

It is mandatory to highlight that fermentation has a major impact on the organoleptic quality of milk-derived products. Traditionally, fermentation was primarily applied to improve and prolong shelf-life, since the growth of fermentative microorganisms typically results in the production of acids or alcohols that inhibits the growth of food pathogens or spoilage organisms preserving the food. Though the chemical transformation of components in dairy food raw materials, and the release of microbial metabolites contribute to the flavor, appearance, and texture. In dairy products, lactose, citrate, milk fat (lipids), and proteins are converted into a broad range of volatile and nonvolatile flavor compounds.

Three main pathways for the flavor formation of dairy products can be distinguished, i.e., glycolysis, proteolysis, and lipolysis [2,3] (see Figure 21.1). These processes may already generate final flavor compounds, though further reactions can occur yielding an even greater number of low-molecular weight components that essential to the overall odor of the product.

In general, flavors derived from lactose or citrate (glycolysis), such as lactic acid, acetaldehyde, and diacethyl (2,3-butanedione), are produced by the lactic flora. Lipids are also another source of a wide range of dairy flavors, and by means of lipolysis and oxidation are prone to cause hydrolytic and oxidative rancidity, respectively. In this manner, small amounts of γ- and δ-hydroxy acids present in milk lipids can be readily converted to γ- and δ-lactones; unsaturated fatty acids may hydrate to hydroxy acids, and then via oxidation produce γ- and δ-lactones; β-oxidation, followed by decarboxylation, produces methyl ketones; and oxidation at double bonds can generate straight-chain aldehydes and ketones, which under reducing conditions may be converted to the corresponding alcohols. Moreover, protein-derived flavors also comprise a large amount of pathways; Strecker aldehydes, such as 2-methylpropanal, 2-methylbutanal, and 3-methylbutanal, can be synthesized via amino acids and, in turn, may produce their corresponding alcohols; and sulfur-containing compounds, such as hydrogen sulfide, methanethiol, and dimethyl disulfide (DMDS), can be derived from cysteine and methionine. In addition, other flavor origins have been reported, such as compounds derived from lactose, without any interaction of the lactic flora, that are developed during heat treatment or that result from alkaline degradation of lactose or its components glucose and galactose, e.g., maltol [4] and 2-acetylfuran [5].

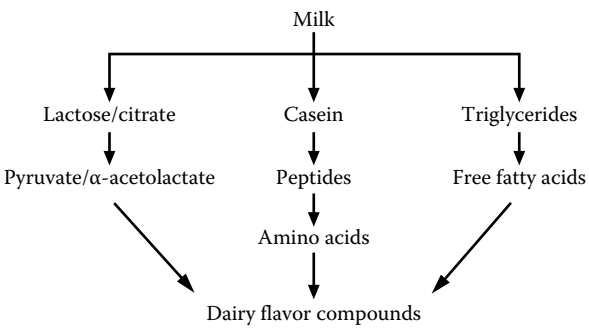


Figure 21.1 Dairy flavor formation pathways in fermented products.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

The flavor of cheeses is composed of a blend of compounds generated by all three pathways; the same is true for key-odor compounds. Cheddar [6] and Camembert [7] cheeses, for instance, have half of their potent odorants derived from lactose fermentation or citrate degradation, a very small amount produced by lipolysis, and the other half resulting from amino acid degradation (leucine and methionine).

Taking into consideration that flavor is the primary index of dairy food acceptance and is strictly related to product development and improvement, this chapter provides an overview of the dairy flavor formation pathways. Numerous dairy food flavors have been thoroughly studied, though demonstrating that even widely investigated metabolic pathways may continuously reveal new facets. In this chapter, flavor formation processes in milk and cheese will be dealt with more extensively.

21.2 Flavor Formation in Milk

Fresh, good quality milk is characterized by three features: a characteristic, subtle, and delicate flavor; a pleasant mouth-feel since it is an emulsion of fat globules dispersed in a colloidal aqueous solution; and a slightly sweet and salty taste due to the presence of lactose and salts. When compared to other dairy products, such as butter or cheese, the concentration of flavor compounds in fresh milk is very low.

It is widely accepted that the flavoring compounds in milk are products of the animals' metabolism, which is also influenced by the feed. As previously cited, another aspect to be considered is the sample's state, so that the flavor of raw milk is not identical to that of heated or processed milk. Esters are considered as responsible for the flavor of raw milk samples, while lactones and heterocyclic compounds for that of heat-treated and pasteurized milk [1].

Furthermore, almost all milk types and milk-derived products are submitted to heat treatments and storage over a period of time inducing flavor development. In addition, autoxidation of lipids, light exposure, and also packaging effects, may yield milk flavors. Moreover, considering that milk is composed of a multitude of compounds belonging to distinct chemical classes, several of these compounds can be precursors of flavor and off-flavor chemicals. The latter may be defined as an unpleasant odor or taste imparted to a food sample though internal deteriorative change [8].

21.2.1 Milk Flavors Developed During Heat Treatment and Storage

Flavor, most frequently off-flavor, development, during heat processes has been already thoroughly researched, and the formation of ketones, lactones, aldehydes, furans, alcohols, acids, and sulfur-containing compounds is widely accepted.

Ketones, such as diketones, cyclic ketones, and methyl ketones, formed in heat-processed milks, are considered as the major contributors to that of matrices cooked and stale flavors [9], while diketone compounds, diacethyl and 2,3-pentanedione, were described as significant contributors to the heated, burnt, and fermented notes elicited by heated milk [10]. With regards to diacethyl, its production is considered to be started by methyl glyoxal, generated by heating lactose, which then reacts with glycin or its derivatives forming diacethyl. Cyclic ketones, e.g., cyclopentanone and 2-methyl-tetrahydrofuran-3-one, are also considered as contributors to the heated, burnt, and fermented notes in heated milk [10].

Milk has been studied in depth by Moio et al. [11–13], who analyzed the matrix under distinct conditions. Analyses of raw bovine, ovine, caprine, and water buffalo milk samples demonstrated that dimethylsulfone, ethyl butanoate, ethyl hexanoate, heptanal, indole, nonanal,

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

and 1-octen-3-ol are odor-active compounds common to all samples. Even though similarities between the distinct samples were found, the overall odor of each milk variety presented a different flavor profile, with ethyl butanoate and ethyl hexanoate as the most potent flavorants in cow, sheep, and goat milk, while water buffalo milk flavor was better characterized by nonanal and 1-octen-3-ol [11]. On the other hand, while investigating high-temperature/short-time (HTST) and ultrahigh temperature (UHT) pasteurized cow milk, dimethylsulfone and 2-heptanone were found to be the most potent odor-active compounds, instead of ethyl butanoate and ethyl hexanoate observed in raw cow milk. Both odorant couples, ethyl butanoate and ethyl hexanoate, and dimethylsulfone and 2-heptanone can be used as aroma quality indicators, for raw and heated milk, respectively [12].

Further compounds that are not detected in raw milk are furans, particularly furfural and hydroxymethylfurfural (HMF), the former eliciting an almond-like, sweet note, while the latter a fatty, musty, and waxy odor. Both are formed when milk is heated above 80°C by the browning of a lactose–casein mixture [14], i.e., the casein catalyzed degradation of lactose induced by heat.

The formation of aldehydes is also noteworthy during prolonged storage of casein, these compounds, particularly alkanal compounds and benzaldehyde, are responsible for an unpleasant stale off-flavor [15]. The production of alkanal compounds can be attributed to the oxidation of lipids bound by casein, while benzaldehyde can be formed by reactions occurring between phenylalanine and lactose [16,17]. Another class of compounds where formation of milk is induced by heat treatments is alcohol, most commonly represented by acetol and acetoin (3-hydroxy-2-butanone). The former is the product of carbohydrate degradation during nonenzymatic browning reactions [10], while the latter may be formed by the reduction of diacetyl [9]. Both the compounds are also detected in raw milk, and in increasing concentrations when heated above 90°C [10]. Heat treatments can also influence the profile of acids in milk; at temperatures superior to 100°C an increment may be observed in the concentrations of acetic, butyric, hexanoic, octanoic, and decanoic acids [10], contributing to the chemical and rancid flavor of heated milk.

Freshly secreted milk fat does not contain free lactones, but their precursors are present in bound form [18]. Indeed, small amounts of δ-hydroxy alkanoic acids esterified to glycerol can be detected, which, upon hydrolysis during heating or storage, form a homologous series of saturated aliphatic δ-lactones. The latter contribute positively to milk flavor eliciting a milky, fatty, and coconut-like note. Moreover, the cooked flavor, commonly observed in milk and derivative products is caused by hydrogen sulfide. This compound is a product of the oxidation of free sulfhydryl groups formed in the denaturation of β-lactoglobulin, the major whey protein of cow's milk [19].

Urbach investigated the effects of cold-storage on raw cow milk samples [20], reporting that carbonyls are reduced to the corresponding alcohols; among the most abundant ones were ethanol, 2-propanol, and 3-methylbutan-1-ol. After prolonged storage, these alcohols were partially esterified with volatile acids.

21.2.2 Flavors Developed from the Autoxidation of Milk Lipids

Milk flavors can also be developed as products of the autoxidation of lipids, rendering a food unpalatable due to a rancid or oxidized odor. In short, the nonenzymatic autocatalytic oxidation reaction of unsaturated fatty acids, most commonly polyunsaturated (oleic, linoleic, linolenic, and arachidonic acids), producing hydroperoxides, which often dismutate to secondary oxidation products, such as aldehydes, ketones, alcohols, acids, hydrocarbons, lactones, furans, and esters. Aliphatic aldehydes are considered as the most important breakdown products of hydroperoxides,

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

due to their major contribution to unpleasant flavors in food products. Moreover, aldehydes resulting from autoxidation may undergo other reactions, contributing further to the flavor of dairy products.

21.2.3 Light-Induced Flavor Formation

Light is known to induce metabolic reactions in dairy products, triggering the degradation of proteins or the oxidation of lipids, resulting in the formation of off-flavors. Furthermore, it is generally accepted that riboflavin plays a major role as photosensitizer in milk and milk-derived products [21]. Photosensitized oxidations produce hydroperoxides, which are prone to decompose forming free radicals, and these are responsible for autoxidation reactions and off-flavor developments. Riboflavin acts by means of two reaction modes. Type I occurs when a triplet riboflavin (electronic excited state with two unpaired electrons) is directly deactivated by the abstraction of an electron from a substrate, which is then oxidized. Subsequently, riboflavin can abstract a further electron, forming a reduced riboflavin or react with ground-state oxygen to generate a superoxide radical. Type I reaction may be exemplified by the photoxidation of lipids yielding alkanals and 2-enals, which are not present in autoxidized milk samples; while 2,4-dienals are only detected in autoxidized samples. According to Wishner [22], the oxidizing substrates in light-exposed milk are the monoene fatty acids of the triglycerides, while in spontaneously oxidized milk polyene fatty acids of the phospholipids are involved.

On the other hand, in type II reactions a triplet riboflavin is deactivated physically by oxygen, and a singlet-oxygen is formed. The latter reacts with the amino acid methionine, which then undergoes Strecker degradation forming aldehydes (e.g., methional) and sulfur-containing compounds (e.g., dimethyl sulfide). It is noteworthy that the broth and potato-like flavors produced when milk is exposed to light are mainly related to the presence of methional; though the understanding of the role of this compound in light-induced flavor is made difficult by its easy conversion to other sulfur compounds [23]. Samuelsson [24] reported that methionine in milk is converted to mercaptan, sulfides, and disulfides at pH 6.8 in the presence of light and oxygen.

21.2.4 Flavor Compounds Derived from Package Component Migration

Flavor formation may be triggered by substances transferred from the package into a dairy matrix (migrants), often monomers (e.g., ethylene glycol), residual reactants (e.g., catalyst residues), or degradation products (e.g., acetaldehyde). The migration of compounds may influence the sensory quality and acceptability of a food product. A commonly detected migrant is acetaldehyde, also known as a degradation product formed in the melting process of poly(ethylene terephthalate) (PET), which is a material that is increasingly used in milk packagings. Acetaldehyde has a pungent, ethereal odor, and is fruity and pleasant when diluted; it strongly decreases the acceptability of milk, while acting as the most important, volatile flavor compound in plain yogurt [25].

Even acetaldehyde concentrations of 10 mg/L exceed the human threshold values of 0.82 mg/L in milk, decreasing strongly the acceptability of milk. Freshly pasteurized milk contains about 10 ppb of acetaldehyde [3], which are most often detected in fermented products, e.g., yogurt at concentrations ranging from 5 to 40 mg/L [26]. Moreover, according to sensorial tests (triangle test performed by 25 panelists) no significant difference in the acetaldehyde threshold in milk of various fat contents could be observed, thresholds of 3939, 4020, and 4040 ppb were determined for nonfat, low-fat, and whole milks, respectively, while chocolate-flavored milk showed a threshold

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

of 10048 ppb [27]. This information assisted in the prediction of the influence of acetaldehyde migration on the flavor of milk products.

21.3 Flavor Formation in Fermented Dairy Products: Cheese

The compounds forming the subtle and delicate milk flavor blend are transformed, by means of fermentation, into other flavor compounds derived either from lactose fermentation and citrate conversion, protein degradation or amino acid catabolism, or lipid degradation. As a consequence, fermented milk-based products present complex, variety, and type-specific flavor profiles, presenting compounds that belong to several chemical classes, such as alcohols, aldehydes, ketones, esters, lactones, furans, nitrogen-containing compounds, as also pyrazines and sulfur-containing compounds, terpenes and their derivatives, aromatic compounds and free fatty acids (FFAs).

One of the most widely studied fermented products is cheese, which has more than 500 varieties [28]. Cheese manufacture consists on the addition of salt, an enzyme coagulant and a culture of a starter organism to milk, the latter is mainly represented by prokaryotes and is the principal source of enzymes involved in the biochemical processes [29]. Predominantly, lactic acid bacteria (LAB) are used as starters, comprising the homolactic (lactococci, streptococci, lactobacilli group I) and the heterofermentative genera (leuconostocci, lactobacilli group III). Within LAB a large strain-to-strain diversity can be observed in flavor formation; thousands of strains are known in the environment both in public and in private culture collections representing an important reservoir of natural diversity of phenotypes.

Additional cultures are also utilized, e.g., *Propionibacterium* in the manufacture of Swiss-cheeses, and, frequently, aerobic cultures in the production of surface-ripened cheeses, such as bacteria (*Brevibacterium*, *Arthrobacter*, and *Staphylococcus*), fungi (*Penicillium*), and yeasts (*Debaromyces*) [30]. Apart from these starter organisms, also lactobacilli originating from the milk environment might grow in dairy products, turning to be a source of enzymes involved in the formation of flavors. Nonstarter organisms (molds and surface bacterial flora) are also reported to be of relevance for flavor formation [31].

Furthermore, it is worthwhile to emphasize that even closely related bacterial strains may exhibit very different flavor-forming activities, due to the fact that (1) the genes encoding key enzymes for flavor formation is not produced by all the strains of a species; (2) different variants of a flavor-forming enzyme among strains may occur, leading to altered catalytic activities; and (3) the expression of many of the enzymes involved in flavor production is strongly subjected to regulation.

21.3.1 Fermentation of Lactose and Conversion of Citrate

Flavor formation during the manufacture of cheeses is initiated immediately after the addition of starter cultures to milk, also known as starter organisms. The widely utilized LAB are able to ferment lactose to lactic acid that on its own is the main flavor of several fresh cheeses. At first, lactose is hydrolyzed by starter cultures producing glucose and galactose. The former is then oxidized to pyruvate by the Emden-Meyerhof pathway of glycolysis, while the latter is converted by galactose-positive bacteria and leuconostocs through the Leloir pathway to glucose-6-phosphate, and to glyceraldehyde-6-phosphate by lactococci through the tagatose pathway (refer to Figure 21.2). The intermediate pyruvate can also be converted to various short-chain flavor compounds, such as diacetyl, acetoin, acetaldehyde, ethanol, and acetate. Diacethyl imparts a buttery, nutty flavor

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

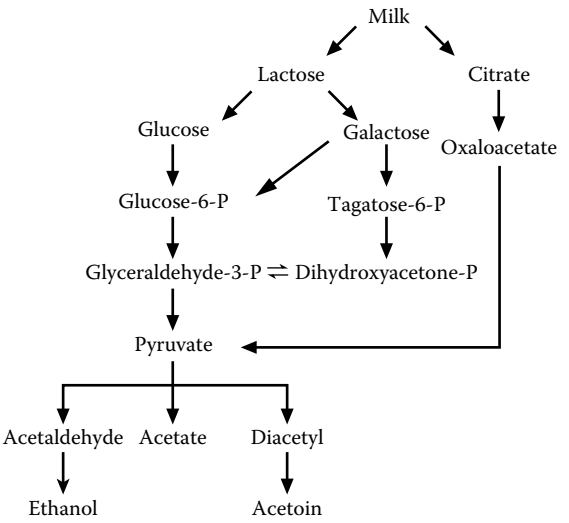


Figure 21.2 Biochemical pathways of lactose catabolism in milk.

and is considered to be significant for the flavor of Camembert [7,32], Cheddar [33,34], Emmental [35], and cottage cheeses [36], while acetoin was considered to contribute to the flavors of Cheddar [34] and Mozzarella cheeses [11] with a sour milk-resembling odor. Moreover, acetaldehyde was described to impart a green note to Camembert [7,32] and Gruyère [37].

In addition, other starter organisms, such as heterofermentative starters, present the ability to ferment other noncarbohydrate substrates, such as citrate, producing acetaldehyde, ethanol, butan-1,2-diol, and diacetyl, yielding a more buttery flavor [36]. In citrate-utilizing LABs this substrate is initially cleaved to oxaloacetate and acetate by a citrate lyase. Moreover, in cultures of *Lactococcus* and *Leuconostoc* spp. oxaloacetate is decarboxylated to pyruvate. Two molecules of the latter are then condensed by an α-acetolactate synthase, forming α-acetolactate and carbon dioxide. The former is unstable, and its decarboxylation may be oxidative yielding diacetyl or non-oxidative forming acetoin, while the latter is responsible for the eye formation in some semihard cheeses [38]. It should be noted that the initial breakdown of citrate and the further conversion of the intermediate pyruvate into specific fermentation products can be regulated at different levels, according to the microorganism. As aforementioned, heterofermentative starters produce carbon dioxide that promotes an open texture. The use of *Propionibacterium freudenreichii* subsp. *shermanii*, which ferments lactose, producing propionic acid and carbon dioxide is also noteworthy; the former contributes to the characteristic flavor of Swiss-type cheese, while the latter is, as mentioned earlier, responsible for the eye formation in the cheese [39].

Nonstarter organisms may also ferment lactose producing a variety of compounds; the coliform fermentation generates formic acid, carbon dioxide, and hydrogen, the butyric fermentation leads to butan-1-ol, butyric acid, acetone, propan-2-ol, and carbon dioxide formation, and the ethanolic fermentation pathway generates ethanol and carbon dioxide. When the lactose supply is depleted, and pH, water acidity, and reducing potential are not optimal, surviving homofermentative starters may widen their range of fermentative activity. Moreover, the lactose depletion rate varies according to the cheese type; from 24 h in Swiss-type to 20 days in Cheddar cheese [40].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

21.3.2 Proteolysis and Catabolism of Amino Acids

The important raw materials for cheese flavor generation include not only low-molecular weight compounds, as citrate and lactose, but also high-molecular weight proteins from which many of the most important flavor compounds are derived, especially in hard-type and semihard-type cheeses.

The proteolytic process is initiated by the conversion of casein to large peptides by proteases. Commonly, LAB strains produce a series of peptidases, which are able to further degrade large peptides to smaller oligopeptides and amino acids. These, on their own, contribute to the flavor promoting a sweet or brothy note. On the other hand, peptides with an undesired bitter taste may also accumulate to concentrations higher than their threshold, which may be removed by the addition of adjuncts able to reduce bitterness, the so-called debittering peptidases [41]. Furthermore, amino acid convertases trigger the formation of flavor compounds from amino acids, yielding various alcohols, aldehydes, acids, esters, and sulfur compounds.

In the past, proteolysis was considered as a rate-limiting process in the maturation of many cheeses, especially in semihard cheeses. However, it was demonstrated that enhancing the free amino acid release by intensifying peptidolysis by LAB [42] or adding free amino acids did not affect aroma formation in cheese [43], suggesting that the rate-limiting factor was not the release of free amino acids but their conversion to flavor compounds.

In general, proteolysis proceeds at a slower rate especially in cheeses that are low in moisture or have a rich salt content; both these characteristics are considered to control the maturation rate. In addition, the concentration of free amino acids was found to be closely linked to the maturity of cheeses, and was recognized as cheese flavor precursors. Amino acids are substrates for transamination, dehydrogenation, decarboxylation, and reduction, producing a wide variety of flavor compounds, or further precursors, such as amines and Strecker aldehydes (see Figure 21.3). The ability of microorganisms to generate flavor compounds from amino acids in cheese is considered to be highly dependent on strain; among the most common strains are LAB, coryneform bacteria, yeasts, and *Geotrichum candidum*, among others [44].

The study of the compounds responsible for the characteristic flavor of various cheeses demonstrated that amino acid degradation is a major process for flavor formation in cheese. Moreover, branched-chain amino acids (leucine, isoleucine, and valine), aromatic amino acids (phenylalanine, tyrosine, and tryptophan), and methionine are the major precursors of these aroma compounds [44]. In this respect, monitoring amino acid degradation during cheese ripening may be a reasonable approach to control flavor formation.

21.3.2.1 Metabolism of Branched-Chain Amino Acids

The catabolism of branched-chain amino acids is initiated by a transamination reaction catalyzed by amino acid aminotransferases [44]. This conversion pathway of amino acids is responsible for the transamination of leucine, isoleucine, and valine, forming α-keto acids intermediates; α-ketoisocaproate, α-keto-β-methyl valerate, and α-ketoisovalerate, respectively. The conversion pathways of the branched-chain α-keto acids, on the other hand, may involve three biochemical reactions: the oxidative decarboxylation to carboxylic acids, the decarboxylation to aldehydes, and the reduction to hydroxyacids. With the exception of hydroxyacids, all of these products present strong flavors. It has to be highlighted that the specificity of the aminotransferases may differ according to the microorganism.

The intermediate α-ketoisocaproate, for instance, may be decarboxylated to 3-methylbutanal, which presents a fruity, pleasant odor at low concentrations, and green, malty, acrid, pungent odor

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

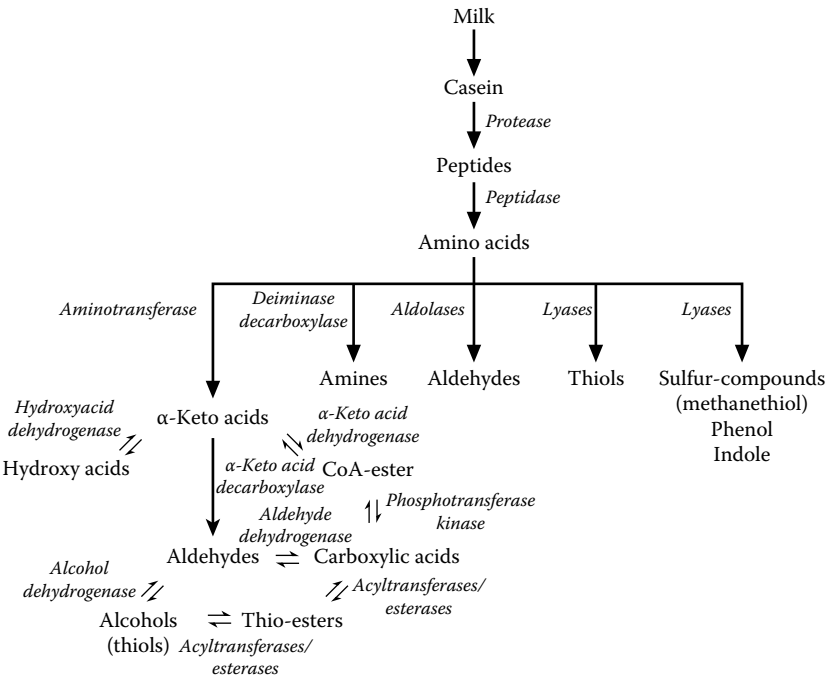


Figure 21.3 Overview of protein metabolic pathways involved in the flavor formation of fermented dairy products.

at higher concentrations; 3-methylbutanal may undergo oxidation catalyzed by aldehyde dehydrogenases to isovaleric acid, which elicits rancid, cheesy, sweaty, and putrid notes that probably contribute to ripe cheese aroma; this is more prevalent in Camembert than in Cheddar, and is also detected in Swiss Gruyère cheese [45].

Similar reactions may also be observed for isoleucine and valine, both are decarboxylated producing the malty flavors 2-methylbutanal and 2-methylpropanal, respectively, which thereafter are oxidized to 2-methylbutyric acid and isobutyric acid. In general, fatty acids originated from branched-chain amino acids yield sweaty, rancid, fecal, putrid, and ester-resembling flavors [44]; the influence of these flavors on a cheese is based on the ratio of its concentration in that product to its threshold concentration in that same matrix. In addition, the conversion of the aldehydes produces the corresponding alcohols, 3-methyl butanol, 2-methyl butanol, and 2-methyl propanol, responsible for alcoholic and fruity flavors [46].

On the other hand, in Emmental cheese 3-methyl butanol is able to suppress the sweaty odor of butyric acid originated from lipolysis [47], and Cheddar cheese presents improved characteristics when flavor formation from branched-chain and aromatic amino acids is enhanced [48]. Besides, 3-methyl butanol also confers a pleasant odor to fresh cheese [49].

21.3.2.2 The Catabolism of Aromatic Amino Acids

The degradation of aromatic amino acids is initiated with a transamination step catalyzed by aminotransferases producing indole pyruvate, phenyl pyruvate, and *p*-hydroxy-phenyl pyruvate from tryptophan, phenylalanine, and tyrosine, respectively.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Elimination reactions catalyzed by amino acid lyases may also be observed when yeast, micrococci, and *Brevibacterium linens* are used. These lyases are able to cleave the side chain of tyrosine and tryptophan, yielding in a single-step phenol and indole, respectively. Moreover, this pathway has not been detected in any LAB [50], though several of them are known to yield tyramine and tryptamine by means of enzymatic decarboxylation of tyrosine and tryptophan.

Generally, compounds derived from aromatic amino acids are responsible for the impact flavor of diverse cheeses; common flavor compounds are benzaldehyde (bitter almond resembling odor), phenyl acetaldehyde (honey-like, floral, rosy, violet-like note), phenyl ethanol (floral, rosy, violet-like odor), phenyl acetate (honey-like note), and phenyl propanoate (floral), while less pleasant notes are indole and skatole, both eliciting fecal putrid, musty odor at higher dilution, and *p*-cresol (phenolic, medicinal flavor). Phenyl acetaldehyde, for instance, is of importance for the impact flavor of Gruyère [37,51] and bovine Mozzarella cheeses [49], while phenyl ethanol apart from being one of the major volatile compounds identified in Camembert [52], is also commonly detected in soft smear cheeses [53] and was already identified in Gruyère cheese [37].

21.3.2.3 Methionine and Its Catabolic Pathways

The methionine conversion to flavor compounds can proceed in different pathways. Elimination reactions (demethiolation) catalyzed by amino acid lyases yielding methanethiol can further be oxidized to DMDS and dimethyl trisulfide (DMTS). The latter is the major pathway for methionine degradation in some organisms, e.g., *B. linens*; while *Lactobacillus lactis* is capable of cleaving the side chain of methionine producing directly methanethiol. The enzymes involved in both elimination reactions are different; in *B. linens* it is the γ-liase, and in *L. lactis* the enzymes are not specific to methionine. A further catabolism pathway consists of the transamination catalyzed by aminotransferases and the resulting α-keto acids are degraded to methanethiol via one or two (methional forming) additional reaction steps.

Methanethiol is considered as one of the responsible compounds for the characteristic flavor of Camembert [7,32] and Cheddar [33], and is also of relevance for the flavor of Gruyère cheeses [37,51]. Moreover, DMDS and DMTS were also found to contribute significantly to the flavor of the latter cheese [37], providing sulfurous and cabbage-like, sulfurous notes, respectively.

21.3.3 Lipolysis and Catabolism of Fatty Acids

Lipid degradation is an important biochemical process that occurs during cheese ripening. It is triggered by lipolytic enzymes, which are hydrolases able to cleave the ester linkage between a fatty acid and the glycerol core of the triacylglyceride (TAG), producing FFA, and monoacylglycerides and diacylglycerides. These enzymes may be classified as esterases or lipases, which are distinguished according to the length of the hydrolyzed acyl ester chain, the physicochemical nature of the substrate, and enzymatic kinetics. FFAs are not only flavor compounds by themselves, but also precursors of catabolic reactions, producing further flavor compounds, such as methyl ketones, esters and thioesters, lactones, aldehydes, and secondary alcohols, as outlined in Figure 21.4. It is worth noting that lipolysis is particularly important in soft cheeses, such as Camembert [54] and Blue cheeses [30], and especially short- and medium-chain FFAs present strong flavors that are generally considered as undesirable, but in some cheeses contribute directly to their flavors, as can be observed for Cheddar cheese [55].

In general, LAB contribute relatively little to lipolysis, but additional cultures, such as molds in surface-ripened cheeses, often exert high lipolytic activity [30], generating FFAs with 4–20 carbon

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

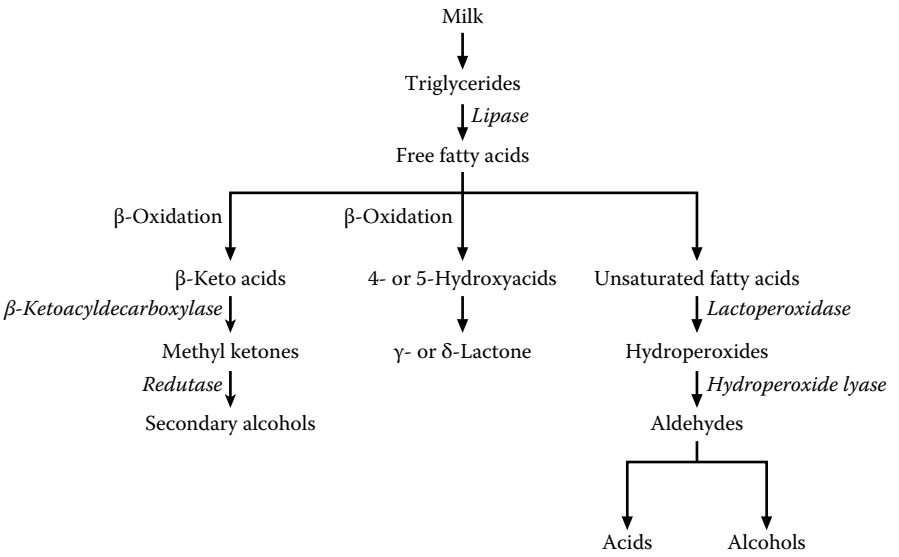


Figure 21.4 Lipid catabolism pathways of some microorganisms utilized in the flavor formation of fermented dairy products.

atoms. The important products of the catabolism of FFAs are the methyl ketones cited earlier (alkan-2-ones), which are formed due to the action of mold lipases. The degradation of lipids by *Penicillium* spp., for instance, is started by the release of FFAs promoted by lipases, these FFA are then oxidized to α-ketoacids, which are decarboxylated to alkan-2-ones, and the latter undergoes reduction yielding alkan-2-ol. Furthermore, mold cultures can also produce methyl ketones using ketoacids naturally occurring in milk at low concentrations as substrate or by the oxidation of monounsaturated fatty acids.

Methyl ketones are important flavor compounds, contributing particularly to the flavor of Blue cheese [56], with their concentration increasing until the 70th day of ripening, then decreasing substantially; similar was observed for Emmental cheese [57]. Studies performed on Camembert cheese led to the identification of 11 methyl ketones; out of these, especially, 2-nonanone (fatty, green note), 2-heptanone (fruity, fatty flavor), and 2-undecanone (herbaceous, fresh note) increased in concentration throughout the ripening process [52]. The ketone 2-heptanone has also been considered of importance for the flavor of Parmigiano Reggiano cheese, when present in concentrations above its sensory threshold [58], as also for Emmental [35] and natural and creamy Gorgonzola cheeses [59]. Another predominant methyl ketone in natural Gorgonzola [59] is also 2-nonanone. Besides, in full-fat Cheddar cheese, the concentrations of 2-heptanone, 2-nonanone, and 2-undecanone increased until about 3.5 months of ripening and then decreased, while in low-fat Cheddar types the concentration of methyl ketones are drastically lower [60].

Esters are further products of the fatty acid catabolism, and are formed by reactions between short- and medium-chain fatty acids with alcohols derived from lactose fermentation or from amino acid catabolism. A great variety of esters, imparting fruity flavors, were identified in diverse cheese types. Imhof and Bosset [31] investigated the flavor of Emmental cheese identifying 14 esters, and Meinhart and Schreier [61] detected 38 esters in Parmigiano Reggiano cheese, with ethyl ethanoate, ethyl octanoate, ethyl decanoate, and methyl hexanoate as the most abundant ones. Thioesters

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

formed by the reaction of esters of short-chain fatty acids with methional imparted the characteristic cheese-like aroma to Cheddar cheese [34], while *S*-methyl thioesters contribute with a characteristic strong flavor to various smear-ripened soft cheeses, such as Limburger and Havarti [62].

Lactones occur naturally in milk, and also in cheeses, but are not considered to be of great relevance to the flavor of cheeses. In Parmigiano Reggiano cheese, for instance, diverse lactones were detected, δ-octalactone being the most significant molecule [61], while Camembert flavor comprised γ-decalactone, δ-decalactone, γ-dodecalactone, and δ-dodecalactone [63]. Moreover, the commonly detected δ-decalactone is one of the most important lactones not only for the flavor of Camembert, as also for the one of Emmental [47] and Blue cheeses [63]. On the other hand, British farmhouse Cheddar cheese flavor is characterized by the presence of δ-dodecalactone [64].

Aldehydes may also be detected in several cheese types, such as straight-chain aldehydes, specially *n*-nonanal, characterized by a green grassy odor in water buffalo Mozzarella cheese [49]. Most commonly aldehydes are transitory compounds, which rapidly reduce to primary alcohols or oxidize into the corresponding acids. In addition, the enzymatic reduction of methyl ketones may yield secondary alcohols; such as 2-propanol and 2-butanol in Cheddar cheese due to reduction of acetone and butanone, respectively [65], or 2-heptanol and 2-nonanol in mold-ripened cheeses, e.g., Camembert [52], Brie [66], and Blue cheeses [63].

21.4 Concluding Remarks

It is widely agreed that a single volatile compound does not elicit the characteristic flavor of a dairy product. Furthermore, it is important to outline that synergistic or suppressive effects of different flavors present in a dairy food matrix should be taken into consideration. The characteristic flavor of a cheese is defined by the so-called component balance theory [28], which is ruled by a wide range of parameters, such as cheese age, microflora, and biochemistry.

Dairy product development is nowadays directed toward new items with distinct flavors. In many cases, this requires the development of special starter cultures delivering specific flavor compounds in a selected product. It is worthwhile to highlight that the presence of starter cultures is not sufficient to explain flavor formation in raw milk cheeses and their selection has never been made with respect to the flavor criterion. Starter cultures metabolic pathways have been exploited to increase knowledge on dairy food flavor formation, and at present, diverse metabolic engineering strategies are reported providing solutions, such as metabolic interventions in *Lactococcus lactis* and other LAB improving the flavor of fermented foods. Several authors make reference to the use of tailor-made mixed cultures of known species of bacteria to provide specific dairy flavors.

Moreover, the further growing demand for new flavor compounds triggers the development and application of analytical methodologies, which are exhaustively described in Chapter 22. As is well known, the complexity of the samples that are analyzed typically mandates that some type of separation be achieved before the component analytes can be measured and characterized, in this respect the utilization of gas chromatography and mass spectrometry is widely diffused.

References

1. Friedrich, J. E. and Acree, T. E., Gas chromatography olfactometry (GC/O) of dairy products, *Int. Dairy J.*, 8, 235, 1998.
2. Smit, G., Smit, B. A., and Engels, W. J. M., Flavour formation by lactic acid bacteria and biochemical flavour profiling of cheese products, *FEMS Microbiol. Rev.*, 29, 591, 2005.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

3. Marilley, L. and Casey, M. G., Flavours of cheese products: Metabolic pathways, analytical tools and identification of producing strains, *Int. J. Food Microbiol*., 90, 139, 2004.
4. Patton, S., The isolation of Maltol from heated skim milk, *J. Dairy Sci*., 33, 102, 1950.
5. Patton, S., Studies of heated milk. III. Mode of formation of certain furan compounds, *J. Dairy Sci*., 33, 904, 1950.
6. Christensen, K. R. and Reineccius, G. A., Aroma extract dilution analysis of aged Cheddar cheese, *J. Food Sci*., 60, 218, 1995.
7. Kubíčková, J. and Grosch, W., Evaluation of potent odorants of Camembert cheese by dilution and concentration techniques, *Int. Dairy J*., 7, 65, 1997.
8. Baigrie, B., Introduction, in *Taints and Off-Flavours in Food*, 1st edn., Baigrie, B., Ed., Woodhead Publishing Ltd., Cambridge, MA, 2003, Chapter 1.
9. Adda, J., Flavour of dairy products, in *Developments in Food Flavours*, 1st edn., Birch, G. G. and Lindley, M. G., Eds., Elsevier Applied Science, London, 1987, pp. 151–172.
10. Shibamoto, T., Flavor volatiles formed by heated milk, in *The Analysis and Control of Less Desirable Flavors in Foods and Beverages*, 1st edn., Charalambous, G., Ed., Academic Press, New York, 1980, pp. 241–265.
11. Moio, L. et al., Powerful odorants in bovine, ovine, caprine and water buffalo milk determined by means of gas chromatography–olfactometry, *J. Dairy Res*., 60, 215, 1993.
12. Moio, L. et al., Detection of powerful odorants in heated milk by use of extract dilution sniffing analysis, *J. Dairy Res*., 61, 385, 1994.
13. Moio, L. et al., Odorous constituents of ovine milk in relationship to diet, *J. Dairy Sci*., 79, 1322, 1996.
14. Ferretti, A. and Flanagan, V. P., The lactose–casein (Maillard) browning system: Volatile components, *J. Agric. Food Chem*., 19, 245, 1971.
15. Parks, O. W. and Patton, S., Volatile carbonyl compounds in stored dry whole milk, *J. Dairy Sci*., 44, 1, 1961.
16. Ramshaw, E. H. and Dunstone, E. A., Volatile compounds associated with the off-flavour in stored casein, *J. Dairy Sci*., 36, 215, 1969.
17. Rijnen, L. et al., Lactococcal aminotransferases AraT and BcaT are key enzymes for the formation of aroma compounds from amino acids in cheese, *Int. Dairy J*., 13, 805, 2003.
18. Dimick, P. S., Walker, N. J., and Patton, S., Occurrence and biochemical origin of aliphatic lactones in milk fat—A review, *J. Agric. Food Chem*., 17, 649, 1969.
19. Hutton, J. T. and Patton, S., The origin of sulfhydryl groups in milk proteins and their contribution to "cooked" flavor, *J. Dairy Sci*., 35, 699, 1952.
20. Urbach, G., Headspace volatiles from cold-stored raw milk, *Aust. J. Dairy. Technol*., 45, 80, 1990.
21. Bekbölet, M., Light effects on food, *J. Food Prot*., 53, 430, 1990.
22. Wishner, L. A., Light-induced oxidations in milk, *J. Dairy Sci*., 47, 216, 1964.
23. Allen, C. and Parks, O. W., Evidence for methional in skim milk exposed to sunlight, *J. Dairy Sci*., 58, 1609, 1975.
24. Samuelsson, E. G., Model experiments on sunlight flavor in milk di- and tripeptides and methionine, *Int. Dairy Cong*., A, 152, 1962.
25. Bills, D. D. et al., Effect of sucrose on the production of acetaldehyde and acids by yogurt culture bacteria, *J. Dairy Sci*., 55, 1570, 1972.
26. Bodyfelt, F. W., Tobias, J., and Trout, G. M., *The Sensory Evaluation of Dairy Products*, Van Nostrand Reinhold, New York, 1988.
27. van Aardt, M. et al., Flavor threshold for acetaldehyde in milk, chocolate milk, and spring water using solid phase microextraction gas chromatography for quantification, *J. Agric. Food Chem*., 49, 1377, 2001.
28. Singh, T. K., Drake, M. A., and Cadwallader, K. R., Flavor of Cheddar cheese: A chemical and sensory perspective, *Comp. Rev. Food Sci. Food Saf*., 2, 165, 2003.
29. Hammes, W. P., Bacterial starter cultures in food production, *Food Biotechnol*., 4, 383, 1990.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

30. Molimard, P. and Spinnler, H. E., Compounds involved in the flavour of surface mold-ripened cheeses: Origins and properties, *J. Dairy Sci.*, 79, 169, 1996.
31. Imhof, B. and Bosset, J. O., Relationship between microorganisms and formation of aroma compounds in fermented dairy products, *Z. Lebensm. Unters. Forsch.*, 198, 267, 1994.
32. Kubíčková, J. and Grosch, W., Evaluation of flavour compounds of Camembert cheese, *Int. Dairy J.*, 8, 11, 1998.
33. Milo, C. and Reineccius, A., Identification and quantification of potent odorants in regular-fat and low-fat mild Cheddar cheese, *J. Agric. Food Chem.*, 45, 3590, 1997.
34. Arora, G., Cormier, F., and Lee, B., Analysis of odor-active volatiles in Cheddar cheese headspace by multidimensional GC/MS/sniffing, *J. Agric. Food Chem.*, 43, 748, 1995.
35. Preininger, M., Rychlik, M., and Grosch, W., Potent odorants of the neutral volatile fraction of Swiss cheese (Emmentaler), in *Trends in Flavour Research*, 1st edn., Maarse, H. and van der Heij, D. G., Eds., Elsevier, Amsterdam, 1994, pp. 267–270.
36. Hugenholtz, J., Citrate metabolism in lactic acid bacteria, *FEMS Microbiol. Rev.*, 12, 165, 1993.
37. Rychlik, M. and Bosset, J. O., Flavour and off-flavour compounds of Swiss Gruyère cheese. Evaluation of potent odorants, *Int. Dairy J.*, 11, 895, 2001.
38. Boumerdassi, H. et al., Effect of citrate on production of diacetyl and acetoin by *Lactococcus lactis* ssp. *lactis* CNRZ 483 cultivated in the presence of oxygen, *J. Dairy Sci.*, 80, 634, 1997.
39. Vangtal, A. and Hammond, G., Correlation of the flavour characteristics of Swiss-type cheeses with chemical parameters, *J. Dairy Sci.*, 69, 2982, 1986.
40. Laht, T. et al., Role of arginine in the development of secondary microflora in Swiss-type cheese, *Int. Dairy J.*, 12, 831, 2002.
41. Sridhar, V. R. et al., Identification of endopeptidase genes from the genomic sequence of *Lactobacillus helveticus* CNRZ32 and the role of these genes in hydrolysis of model bitter peptides, *Appl. Environ. Microbiol.*, 71, 3205, 2005.
42. Christensen, J. E., Johnson, M. E., and Steele, J. L., Production of Cheddar cheese using a *Lactococcus lactis* ssp. *cremoris* SK11 derivative with enhanced aminopeptidase activity, *Int. Dairy J.*, 5, 367, 1995.
43. Wallace, J. M. and Fox, P. F., Effect of adding free amino acids to Cheddar cheese curd on proteolysis, flavour and texture development, *Int. Dairy J.*, 7, 157, 1997.
44. Yvon, M. and Rijnen, L., Cheese flavour formation by amino acid catabolism, *Int. Dairy J.*, 11, 185, 2001.
45. Bosset, J. O., Collomb, M., and Sieber, R., The aroma composition of Swiss Gruyère cheese IV. The acidic volatile components and their changes in content during ripening, *Lebensm. Wissenschaft Technol.*, 26, 581, 1993.
46. Thierry, A. and Maillard, M. B., Production of cheese flavour compounds derived from amino acid catabolism by *Propionibacterium freudenreichii*, *Lait*, 82, 17, 2002.
47. Preininger, M., Warmke, R., and Grosch, W., Identification of the character impact flavour compounds of Swiss cheese by sensory studies of models, *Lebensm. Unters. Forsch.*, 202, 30, 1996.
48. Banks, J. M. et al., Enhancement of amino acid catabolism in Cheddar cheese using α-ketoglutarate: Amino acid degradation in relation to volatile compounds and aroma character, *Int. Dairy J.*, 11, 235, 2001.
49. Moio, L. et al., Volatile flavour compounds of water buffalo Mozzarella cheese, *Ital. J. Food Sci.*, 5, 57, 1993.
50. Gummala, S. and Broadbent, J. R., Tryptophan catabolism by *Lactobacillus casei* and *Lactobacillus helveticus* cheese flavor adjuncts, *J. Dairy Sci.*, 82, 2070, 1999.
51. Rychlik, M. and Bosset, J. O., Flavour and off-flavour compounds of Swiss Gruyère cheese. Identification of key odorants by quantitative instrumental and sensory studies, *Int. Dairy J.*, 11, 903, 2001.
52. Dumont, J. P. et al., Etude des composés neutres volatils prèsents dans le Camembert, *Lait*, 538, 501, 1974.
53. Sablè, S. and Cottenceau, G., Current knowledge of soft cheeses flavor and related compounds, *J. Agric. Food Chem.*, 47, 4825, 1999.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

54. Gripon, J. C., Mould-ripened cheeses, in *Cheese: Chemistry, Physics and Microbiology. 2. Major Cheese Groups*, 2nd edn., Fox, P. F., Ed., Elsevier, London, 1993, pp. 111–136.
55. Bills, D. D. and Day, E. A., Determination of the major free fatty acids of Cheddar cheese, *J. Dairy Sci*., 47, 733, 1964.
56. Dartley, C. K. and Kinsella, J. E., Rate of formation of methyl ketones during Blue cheese ripening, *J. Agric. Food Chem*., 19, 771, 1971.
57. Thierry, A., Maillard, M. B., and Le Quere, J. L., Dynamic headspace analysis of Emmental aqueous phase as a method to quantify changes in volatile flavour compounds during ripening, *Int. Dairy J*., 9, 453, 1999.
58. Qian, M. and Reineccius, G., Potent aroma compounds in Parmigiano Reggiano cheese studied using a dynamic headspace (purge-trap) method, *Flavour Fragr. J*., 18, 252, 2003.
59. Moio, L., Piombino, P., and Addeo, F., Odour-impact compounds in Gorgonzola cheese, *J. Dairy Res*., 67, 273, 2000.
60. Dimos, A., Urbach, G. E., and Miller, A. J., Changes in flavour and volatiles of full-fat and reduced-fat Cheddar cheeses during maturation, *Int. Dairy J*., 6, 981, 1996.
61. Meinhart, E. and Schreier, P., Study of flavour compounds from Parmigiano Reggiano cheese, *Milchwissenschaft*, 41, 689, 1986.
62. Lamberet, G., Auberger, B., and Bergere, J. L., Aptitude of cheese bacteria for volatile S-methyl thioester synthesis. II. Comparison of coryneform bacteria, Micrococcaceae and some lactic acid bacteria starters, *Appl. Microbiol. Biotechnol*., 48, 393, 1997.
63. Gallois, A. and Langlois, D., New results in the volatile odorous compounds of French cheese, *Le Lait*, 70, 89, 1990.
64. Suriyaphan, O. et al., Characteristic aroma components of British Farmhouse Cheddar cheese, *J. Agric. Food Chem*., 49, 1382, 2001.
65. Urbach, G., Relations between cheese flavour and chemical composition, *Int. Dairy J*., 3, 389, 1993.
66. Karahadian, C., Josephson, D. B., and Lindsay, R. C., Contribution of *Penicillium* sp. to the flavors of Brie and Camembert cheese, *J. Dairy Sci*., 68, 1865, 1985.

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Chapter 22

Flavor

Barbara d'Acampora Zellner, Paola Dugo,
Giovanni Dugo, and Luigi Mondello

Contents

22.1 Brief Introduction to Dairy Flavor 386
22.2 Dairy Flavor Extraction Techniques 387
22.3 Analytical Methodologies for Dairy Products Flavor Investigation 389
22.3.1 Instrumental Techniques for Analytical Flavor Assessment 389
22.3.1.1 Gas Chromatography in Dairy Flavor Investigation 389
22.3.1.2 Gas Chromatography Coupled with Mass Spectrometry 391
22.3.1.3 Dairy Food Flavor Analysis by Means of Comprehensive Two-Dimensional Gas Chromatography 392
22.3.1.4 Odor-Activity Assessment by Means of Gas Chromatography-Olfactometry 394
22.3.1.5 Dairy Flavor Fingerprint Acquisition through Mass Spectrometry 400
22.3.1.6 Electronic Nose and Tongue in Dairy Flavor Analysis 402
22.3.2 Sensorial Dairy Flavor Analysis 403
22.3.2.1 Odor-Activity Value Determination 403
22.3.2.2 Analytical Sensory Tests 404
22.4 Characterization of Off-Flavors 406
22.5 General Considerations on Dairy Flavor 408
References 408

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

22.1 Brief Introduction to Dairy Flavor

The consumption of dairy foods is strongly related to the stimulation of the human chemical senses, odor, and taste. The flavor of dairy products, along with its appearance and texture, is considered to be decisive for the consumer in its selection and ingestion. According to Laing and Jinks [1], food flavor is commonly defined as being the sensation arising from the integration or interplay of signals produced as a consequence of sensing smell, taste, and irritating stimuli from food or beverage. However, the term flavor is often inconsistently used, with regard to the above-mentioned biological receptor stimulation or to the chemicals responsible for the process.

With respect to the dairy food aroma, the sensation of odor is triggered by highly complex mixtures of volatile molecules, mostly hydrophobic and usually occurring in trace-level concentrations (ppm or ppb). These volatile molecules interact with a G protein-coupled odorant receptor (OR) of the olfactive epithelium located in the nasal cavity. Once the receptor is activated, a cascade of events is triggered to transform the chemical–structural information contained in the odorous stimulus into a membrane potential [2,3]. The latter is projected to the olfactory bulb, and then transported to higher regions of the brain [4], where the translation occurs.

The human nose perception of volatile compounds, released from dairy foods, depends on the extension of the release from the matrix and the odor properties of the compounds. It is known that only a small portion of the large number of volatiles occurring in a food matrix contributes to its overall perceived odor [5,6]. Further, these molecules do not contribute equally to the overall flavor profile of a sample; hence, the most abundant compound does not necessarily correspond to high odor intensities, owing to differences in intensity/concentration relationships.

Since the mid-1950s, volatile flavor components have been studied in dairy products, and the chemistry and identification of milk and cheese flavors have been widely described in literature. It is worth mentioning that one of the earliest applications of formal laboratory sensory analysis was carried out in the dairy-products industry. In the early 1990s, techniques for the judgment of these products were developed to stimulate the interest and educate consumers. The attributes considered were appearance, flavor, and texture, in relation to the presence or absence of predetermined defects. Over the last decades, flavor research has benefited from the improvements in the instrumental analytical chemistry, and a vast number of investigations have been carried out on dairy flavor compounds; many of these were investigated following the advent of gas chromatography (GC) that enabled component separation and identification, though requiring additional confirmatory evidence to avoid equivocated characterizations, such as by means of its coupling with mass spectrometry (MS) or olfactometry. It is worthwhile to highlight that GC combined with MS (GC/MS), marked a real turning point for dairy-foods research, and the introduction of GC with olfactometry (GC-O) was a breakthrough in the analytical aroma research, enabling the differentiation of a multitude of volatiles that are odor and nonodor active, according to their existing concentrations in a matrix. It is notable that the identification of flavor components of dairy products is generally very difficult, mainly owing to the tendency of these compounds to degrade or form artifacts during isolation processes, and also their presence in low concentrations with respect to other food matrices. However, nowadays, the number of known flavors has incredibly increased, with around 600 identified in cheese flavor [7].

In view of all the studies already performed on the flavor of several dairy products, it is possible to state that their profile comprises a large number of volatiles, which may include free carboxylic acids, sulfur compounds, alkaline nitrogen-containing substances such as amines and substituted pyrazines, pyridines, neutral compounds such as carbonyl compounds (e.g., methyl ketones and aldehydes), primary and secondary alcohols, esters, lactones, ethers, aliphatic and aromatic hydrocarbons, as well as multifunctional components [8].

© 2011 by Taylor and Francis Group, LLC

Downloaded From Vet-eBooks.com

Moreover, it is widely accepted that the flavoring chemicals profile vary according to the sample's state, and hence, raw milk elicits a distinct odor when compared with that of heated or processed milk, with different classes of compounds responsible for the characteristic odor of distinct samples. It is widely accepted that esters are responsible for the flavor of raw-milk samples, while lactones and heterocyclic compounds are responsible for that of heat-treated and pasteurized milk. On the other hand, fermented dairy products, such as cheese and yogurt, are characterized by the presence of fatty acids [9]. However, it is worth to point out that little is known about the characteristic impact of the flavor of most dairy products. Distinction has to be made between key odorants and odor-active compounds, as it is well known that only a small fraction of the volatile substances of a food matrix is responsible for its characteristic odor.

To attain a complete analysis of key odorants, sensorial analyses such as studies of recombination models and omission experiments, should be performed to increase the reliability of the achieved characterization. This chapter provides an overview on the most commonly applied analytical techniques to characterize the dairy food flavor. However, extended sample preparation theory will not be dealt with, and the diverse dairy products investigation methodologies will be outlined. On the other hand, analytical flavor assessment techniques will be focused on GC analyses, including theoretical principles and applications. Moreover, some aspects regarding the characterization of off-flavors will be briefly described.

22.2 Dairy Flavor Extraction Techniques

A significant but laborious step of dairy flavor analysis is sample preparation. The odor profile of a matrix is closely related to the isolation procedure that should yield a product that is representative of the sample; therefore, the choice of an appropriate sample preparation method becomes unprecedented.

According to the properties of the matrix, the preparation may include mincing, homogenization, centrifugation, steam distillation (SD), solvent extraction (SE), fractionation of solvent extracts, simultaneous distillation-extraction (SDE), supercritical fluid extraction (SFE), pressurized-fluid extraction, Soxhlet extraction, solvent-assisted flavor evaporation (SAFE), headspace techniques (HS), solid-phase microextraction (SPME), matrix solid-phase dispersion (MSPD), cryofocusing, and/or direct thermal desorption (DTD), among others. Attention should be given during sample preparation and treatment procedures to avoid the loss of highly volatile compounds and oxygen or heat-induced artifact formation.

Taking into consideration that, in general, volatile molecules contained in solid and semisolid dairy products are heterogeneously distributed, and, as previously cited, usually occur in trace-level concentrations, careful homogenization of the sample is required prior to flavor analysis. With regard to cheese samples, a commonly used, convenient, and mild technique is based on freezing, followed by grating of the sample at low temperature, and a powder is subsequently obtained in this process. According to the applied flavor investigation methodology, this powder may be dispersed using a high-speed homogenizer, e.g., in water. Furthermore, owing to the high diversity of volatile components of dairy food samples, a preliminary separation into acidic, alkaline, and neutral fractions can often be of great aid for instrumental and sensorial analysis [10].

In general, SD and SE methods are considered to yield the near-complete flavor of food extracts, which may not be of relevance for the determination of a characteristic odor profile. The extraction of the volatiles from a dairy matrix usually results in a dilute aqueous solution, and the volatiles have to be concentrated by liquid/liquid partitioning or cryoconcentration prior

© 2011 by Taylor and Francis Group, LLC

to GC analysis. Commonly, the extracts obtained by SE can be very complex, resulting in many coelutions when analyzed by means of GC, making the identification of individual odor-active compounds difficult. The fractionation of these extracts is time-consuming, but is a useful method to overcome this limitation, e.g., by washing a food extract with dilute acid or base, even though multiple manipulations of the extract may cause loss of highly volatile compounds. Moreover, a possible loss of the more volatile compounds during solvent removal may occur, and hence, large amounts of sample are needed to attain concentrated extracts, which may represent a drawback, and the presence of nonvolatile and high-boiling compounds in the extract or impurities from the solvent may lead to unreliable flavor characterization. Furthermore, in GC-O analysis, the solvent peak may cover early eluting odor-active volatiles. On the other hand, by performing SD extractions, the presence of nonvolatile or high-boiling compounds in the dairy food extract is avoided, though poor extraction of highly polar or hydrophilic compounds (acids and alcohols) as well as artifact formation owing to thermal degradation may occur. However, concentrated sample may surely be advantageous, as it enables further detection of trace components. It is accepted that SD and SE, when combined with chromatography, are generally the best methods to isolate unknown components of dairy foods [9].

The technique SDE is also widely applied. The latter provides fast extractions, resulting in a fraction, which after concentration, can be readily injected into GC systems. In a continuous process, the condensing water vapor is extracted by the condensing vapor of the low-boiling solvent, resulting in a high extraction rate. However, the decomposition of labile compounds, loss of highly volatile compounds, and heat-induced artifact formation has often to be observed. A modified system, the SDE under static vacuum (SDE-SV) with continuous sample feeding, although being more time-consuming, may be used when heat-induced artifact formation has to be minimized. The latter method allows extractions at 30°C–35°C and eliminates the concentration step prior to GC analysis.

Another very popular extraction method is SAFE, which may be applied after SE techniques or be used as an individual extraction method for solvent extracts or food matrices. This technique, most commonly applied to aqueous foods such as milk, removes volatiles under low-temperature and high-vacuum conditions. The extract is then collected into flasks that are cryogenically cooled with liquid nitrogen. The attained product should be representative of the original sample, uncooked, but without high-boiling compounds and color.

The HS methods, which are also frequently applied, may be divided into static headspace (SHS) and dynamic headspace (DHS) analyses. The former is characterized by the sampling of the atmosphere, after equilibrium has been achieved, around the headspace of a matrix, located in a vial, while the latter removes larger amounts of volatiles by sweeping the matrix through a carrier gas flow, with a concentration step carried out prior to GC analyses. The HS techniques combine the solvent-free procedures and require small amounts of sample with no artifact formation. However, it is worth to highlight that the relative concentration of volatile components in the headspace does not correspond to the concentration in the sample, owing to the volatility differences of flavor compounds (vapor pressure), as well as to the extraction temperature. In addition, when HS techniques are utilized frequently, the pH level of the homogenate has to be adjusted to pH 7.5 to maintain the high concentration of volatile acids dissolved in the aqueous solution as salts, so that the fraction to be analyzed is mainly represented by the neutral and alkaline components [11]. However, preparation of an alkaline homogenate can cause the decomposition of some essential components, such as lactones [12]. On the other hand, volatile acids may be esterified in the gas phase prior to analysis [13].

© 2011 by Taylor and Francis Group, LLC

A further technique worth mentioning is SPME, a widely applied solvent-free method, which exploits the high adsorption power of a fused silica fiber coated with a specific extraction phase, selected according to the type of matrix [14,15]. However, the use of SPME as an isolation method for dairy flavor characterization presents some limitations owing to the possible nonrepresentative nature of the extracts, problematic quantification, prolonged heating of the samples during isolation to increase flavor volatility, and recovery. The chemical profile of the collected volatiles depends on the type, thickness, and length of the fiber, as well as on the sampling time and temperature.

Moreover, taking into consideration the demand to simulate the flavor released during the consumption of a food, sophisticated extraction techniques have been developed, such as the buccal headspace analysis (BHA) [16]. The latter is an *in vivo* extraction technique capable of extracting volatile compounds released during consumption in concentration ratios that stimulate the olfactory receptors.

To establish the most adequate extraction procedure, an analyst has to consider not only the low concentrations of the dairy flavor components, but also their tendency to degrade or form artifacts during the processes. Some frequently observed phenomena are: formation of methyl ketones owing to thermal decarboxylation of β-keto acids in dairy lipids, disulfide compound formation as the product of oxidation of mercaptans, and the activation of lipases and other enzymes by mild heating during milk storage, which subsequently react with the triglycerides producing increased amounts of free fatty acids. Furthermore, according to the applied extraction method, highly polar or semivolatile flavor chemicals, such as free fatty acids, vanillin, 2,5-dimethyl-4-hydroxy-3(2*H*)-furanone (DMHF) or furaneol, may present incomplete recovery.

Although a series of volatile isolation methods have been developed to enhance the quality of flavor analyses, none of the commonly used extraction methods is capable of faithfully reproducing a flavor's profile. Therefore, the application of diverse extraction procedures on an identical matrix is highly suggested to achieve a more extensive screening.

22.3 Analytical Methodologies for Dairy Products Flavor Investigation

22.3.1 Instrumental Techniques for Analytical Flavor Assessment

22.3.1.1 Gas Chromatography in Dairy Flavor Investigation

After its introduction in 1952 by James and Martin [17], GC developed at a phenomenal rate, growing from a simple research novelty to a highly sophisticated instrument. In GC analysis, the compounds to be analyzed are vaporized and eluted by the mobile gas phase, i.e., the carrier gas, through the column that contains the stationary phase dispersed on a solid support. At the outlet of the analytical column, the analytes emerge separated on the basis of their relative vapor pressures and affinities for the stationary bed, and as a consequence, are separated in time. The analytes are then detected and a signal is recorded generating a chromatogram, i.e., a signal *vs.* time graphic, and ideally with peaks presenting a Gaussian distribution-curve shape. The peak area and height are a function of the amount of solute present, its width is a function of the band spreading in the column [18], and its retention time can be related to the solute's identity.

In general, the primary objective in any GC separation is always the complete resolution of the compounds of interest, at minimum time duration. To achieve this task, the most suitable

© 2011 by Taylor and Francis Group, LLC

analytical column (dimension and stationary-phase type) has to be chosen, and adequate chromatographic parameters must be applied to limit the peak enlargement phenomena. Furthermore, the constant requirements for high resolution and trace analysis are satisfied by modern column technology; robust fused-silica open-tubular GC columns are available. In addition, the selective detectors and injection methods, which allow on-column injection of liquid and thermally labile samples, have also been developed.

The choice of the analytical column in dairy flavors GC analyses is of great importance for the overall characterization of the sample; the stationary-phase chemical nature and film thickness, as well as the column length and internal diameter, are to be considered. In general, dairy flavor GC analyses are carried out on 25–60 m columns, with 0.25–0.53 mm internal diameter and 0.25–5.00 μm stationary-phase film thickness. Numerous stationary phases are available, but only some of them are commonly utilized, such as polyethylene glycol and its acid-modified phases (nitroterephthalic acid-modified polyethylene glycol), dimethylpolysiloxane (5% phenyl–95% dimethylpolysiloxane or 50% phenyl–50% dimethylpolysiloxane), and dimethylpolysiloxane copolymer (cyanopropyl-phenyl-methylpolysiloxane and 50% cyanopropyl-methylpolysiloxane). It is well known that the degree of separation of the two components on two distinct stationary phases can be drastically different; the nonpolar and polar columns produce boiling point- and polarity-based separations, respectively. As a consequence, it is highly advisable to use two analytical columns coated with stationary phases of distinct polarities to better characterize the sample and enhance the confidence in peak assignment.

An important study on the suitability and performance of various stationary phases and column dimensions for dynamic headspace GC of ripe Swiss Emmental cheese flavor was carried out by Imhof and Bosset [19]. The best performance was observed on a 30 m × 0.32 mm i.d., 4.0 μm d_f, 100% polydimethylsiloxane stationary phase (SPB-1 SULFUR, Supelco, Bellefonte, PA), which presented better resolution and higher loading capacity, separating the greatest number of compounds in the cheese sample, i.e., 58 components. On the other hand, on the 30 m × 0.32 mm i.d., 1.0 μm d_f, and 60 m × 0.25 mm i.d., 1.0 μm d_f columns coated with identical stationary phase, respectively, 47 and 57 compounds were identified, respectively.

Moreover, dairy flavor GC analyses are commonly carried out using detection systems that do not provide structural information of the analyzed molecules, such as flame ionization detector (FID) or thermal conductivity detector (TCD), and also flame photometric detector (FPD) or pulsed FPD (PFPD); the latter two being selective for sulfur-containing compounds, such as hydrogen sulfide, carbonyl sulfide, and methanethiol. The use of an SPME–GC system equipped with a PFPD has been reported in a study performed over a period of 20 months on volatile sulfur compounds formed in heat-shocked and pasteurized milk cheese [20]. The authors were able to outline that only hydrogen sulfide and dimethyl disulfide increased in the initial stage of cheese-aging and reached a plateau, whereas methanethiol, dimethyl sulfide, and dimethyl trisulfide continued to develop as the cheese aged. Moreover, it could be observed that Cheddar cheese made from heat-shock milk developed higher concentrations of methanethiol, dimethyl sulfide, dimethyl disulfide, and dimethyl trisulfide than cheeses made from pasteurized milk. The simultaneous usage of FID and FPD has also been applied to the study of Cheddar [21] and Limburger cheeses [22]. A further detection system used for dairy flavor analysis is the nitrogen phosphorous detector (NPD), which, owing to its high selectivity for nitrogen-containing compounds, has been applied to investigate the presence of trimethylamine in cow milk samples; this compound, when present in high concentrations, is responsible for a fishy off-flavor [23].

When dairy flavor GC analyses are carried out using FID, TCD, or other detection systems that do not provide analytes structural information, retention indices are commonly used to assist

© 2011 by Taylor and Francis Group, LLC

peak assignment. The most thoroughly studied, diffused, and accepted retention index methods are based on the logarithmic-based equation developed by Kováts in 1958 [24] for isothermal conditions, and on the equation propounded by van den Dool and Kratz in 1963 [25], which does not use the logarithmic form and is used in the case of temperature-programming conditions. Both the proposals are based on the fact that each analyte is cited in terms of its position between the two compounds in a homologous series (e.g., *n*-alkanes) that bracket its retention time. It shall be outlined that the index calculation is based on a linear interpolation of the carbon chain-length of these bracketing paraffins.

When *n*-alkanes are used, it is accepted that the reproducibility of the retention indices between different laboratories are comprised within an acceptable range of ±5 units for methyl silicone stationary phases, and ±10 units for polyethylene glycol phases. Moreover, in practice, any homologous series presenting a linear relationship between the adjusted retention time, being logarithmic-based or not, and the carbon number can be used; e.g., fatty acid ethyl esters (FAEEs) or fatty acid methyl esters (FAMEs), employed according to the stationary phase to be used.

22.3.1.2 Gas Chromatography Coupled with Mass Spectrometry

The advent of combined GC and MS marked a real turning point for flavor research, and during the past decade, tremendous growth in popularity of mass spectrometers as a tool for routine analytical experiments as well as fundamental research could be observed.

A mass spectrometer produces an enormous amount of data, especially in combination with chromatographic sample inlets [26]. Over the years, many approaches to the analysis of GC/MS data have been proposed including diverse library search algorithms, many of which are quite sophisticated, to detect, identify, and quantify all the chromatographic peaks. As a consequence, a large number of studies started to exploit the mass spectral information for peak identification; the most frequent and simple identification method comprises the comparison of the acquired unknown mass spectra with those contained in a reference mass spectral library. In addition, the use of retention indices, in conjunction with the structural information provided by the mass spectrometer, is widely accepted to increase the reliability of the analytical results and address the qualitative determination of the compositions of complex samples by GC/MS; it is widely accepted to use retention indices to confirm the identity of the compounds.

The GC/MS, one of the most popular techniques employed in the investigation of dairy food flavors, has been applied to a wide range of samples. Obviously, it is not feasible to report all the research works carried out on dairy flavor analysis, and hence, some examples were chosen to illustrate its usefulness.

Dirinck and De Winne made use of a GC/MS system to determine the flavor of Gouda and Emmental cheeses, aiming to establish the biotechnological process towards typical cheese-flavor characters [27]. The volatile fractions of three Gouda cheeses from different producers and three Emmental cheeses from different origins (Swiss, French, and Austrian) were isolated by SDE and analyzed, and the results were submitted to principal component analysis (PCA). It could be outlined that the Gouda cheeses from different producers presented similar flavor profile, while the Emmental cheeses presented origin-dependent profiles. However, the Austrian sample could be clearly differentiated from the French and the Swiss samples.

A further interesting example of the use of GC/MS for cheese flavor analysis was reported by Barbieri et al. [28], who studied the volatile profile of 21 Parmesan cheese samples of certified origin and aging. Prior to GC and GC/MS analyses, the flavor components were isolated by means of DHS and SDE. The former technique enabled the isolation of the most volatile compounds, whereas the

© 2011 by Taylor and Francis Group, LLC

latter was also suitable to extract other important flavor components, such as long-chain carbonyl derivatives, acids, esters, and lactones. A total of 167 compounds were identified, including hydrocarbons, aldehydes, ketones, alcohols, esters, and acids. Furthermore, free fatty acids and volatile products of lactic fermentation (ethanol, acetaldehyde, diacethyl, and acetoin) were also determined. In addition, spray-dried skimmed milk flavor was investigated by means of GC/MS [29]. Prior to GC and GC/MS analyses, the sample was homogenized with water, and the volatiles were isolated by SDE using diethyl ether as solvent; a total of 187 out of 196 detected components could be identified by using mass spectral information and retention indices obtained in GC analysis.

Quantitative analyses of dairy flavors have also been performed using GC/MS, as reported by Fernández-García [30], who applied an automatic headspace injector connected to a GC/MS system to quantify the flavor of the Spanish artisanal Afuega'l Pitu cheese throughout ripening period. The standard addition method, using ethyl propionate, and camphor as internal standards, accompanied by standard addition calibration to compensate the matrix effect, was applied to quantify 17 of the 40 compounds identified in the cheese headspace profile. Moreover, within the concentrations used, most of the volatile compounds presented good linearity ($r > 0.99$). According to the author, the cheese aroma profile changed qualitatively and quantitatively during the ripening period of 30 days. During the first two ripening weeks, ethanol, diacethyl, acetoin, 2-methyl-1-propanol, 3-methyl-1-butanol, and acetic acid were the major compounds, while in the following 2 weeks, the concentration of the ethyl esters of fatty acids, acetaldehyde, and sulfur compounds increased.

22.3.1.3 Dairy Food Flavor Analysis by Means of Comprehensive Two-Dimensional Gas Chromatography

The butter flavor has been analyzed not only by GC/MS, but also by comprehensive two-dimensional GC (GC × GC) and GC × GC coupled with a time-of-flight mass spectrometer (GC × GC–TOF-MS). The first approach was applied to characterize the polar flavor compounds of that matrix, which were collected from the aqueous fraction of butter by means of SPE, allowing the enrichment of the trace-level compounds [31]. Moreover, fresh and heated butter were analyzed on the polar stationary phase, and the identification and quantification of trace-level compounds were carried out. Significant changes in the flavor-compound pattern caused by thermal treatment could be observed; a 500–1000-fold increased concentration of maltol and substantial amounts of furaneol were detected.

The second technique, GC × GC, also widely applied to food analysis, produces an orthogonal two-column separation, with the complete sample transfer achieved by means of a modulator; the latter entraps, refocuses, and releases fractions of the GC effluent from the first dimension (^{1}D) onto the second dimension (^{2}D) column, in a continuous mode. This method enables an accurate screening of complex matrices, offering very high resolution and enhanced detection sensitivity [32,33]. Moreover, the two columns must possess different separation mechanism. A two-dimensional separation can be considered as comprehensive, if the other two conditions are appreciated [34,35], *viz*., equal percentages of all the sample components pass through both the columns and eventually reach the detector; and the resolution obtained in the first dimension is essentially maintained.

Adahchour et al. [36] applied GC × GC to analyze butter flavor using the same general setup, as in the previously mentioned GC/MS study [31], with identical target analytes and experimental parameters (heat treatment and storage effects). The authors aimed to compare the two methods of the analysis, monodimensional GC and GC × GC. For polar flavor compounds collected by means of SPE, GC × GC using a polar–midpolar column set dramatically improved the

© 2011 by Taylor and Francis Group, LLC

overall separation, enabling a more reliable analysis of the target compounds, rapid recognition of prominent classes of compounds on the basis of ordered structures, and provisional identification of a much larger number of unknown compounds.

In addition, the headspace of the butter samples, adjacent to the aqueous fraction, was analyzed by means of SPME. The butter volatile headspace was satisfactorily characterized by GC×GC. In Figure 22.1, the chromatograms of the heated grass butter flavors extracted with two different

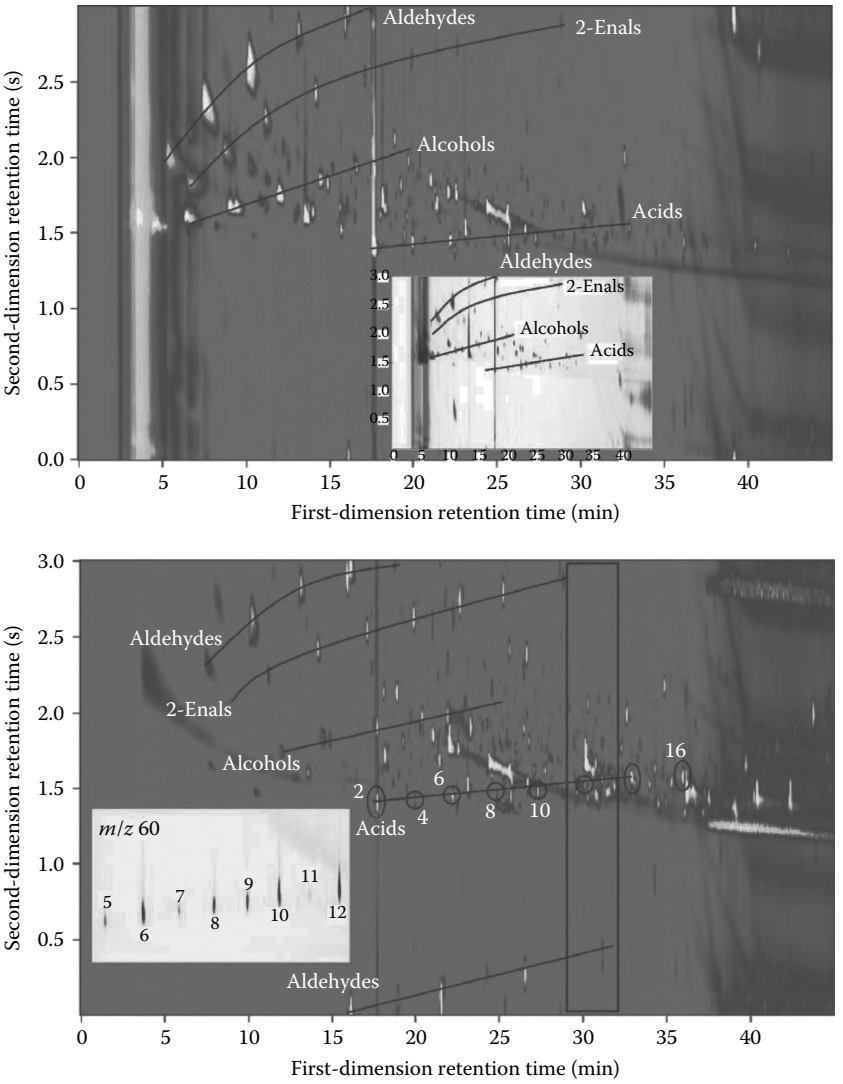


Figure 22.1 GC×GC-FID chromatograms of "grasboter" heated at 170°C and extracted by Carboxen/PDMS fiber (top); in the insert, the profile of the identical sample heated at 40°C is represented. In the chromatogram of the extraction at 170°C by Carbowax/DVB fiber (bottom), the numbers 2–16 indicate carbon numbers of the circled acids. In the insert part of GC×GC–TOF-MS, ion traces *m/z* 60 showing both even- and odd-numbered fatty acids are presented. (Reprinted from Adahchour, M. et al., *J. Chromatogr. A*, 1086, 99, 2005. With permission.)

© 2011 by Taylor and Francis Group, LLC

SPME fibers are shown. It could be observed that the Carboxen/polydimethylsiloxane (PDMS) fiber presented an increased affinity to more volatile compounds, while the Carbowax/divinylbenzene (DVB) fiber had an affinity to the less volatile flavors. It has to be pointed out that the complexity of the headspace increased at higher temperatures. As can be observed in the chromatograms, several classes of compounds, such as aldehydes, 2-enals, alcohols, and fatty acids form ordered structures in the GC × GC plane. For illustration, some of the fatty acids are circled and indicated according to their carbon number in the bottom chromatogram in Figure 22.1. The acids detected in these samples ranged from formic (C_1) to hexadecanoic (C_{16}) acid, with dominant even-numbered carbons along with the odd-numbered fatty acids, which are indicated in the insert showing the GC × GC–TOF-MS ion traces *m*/*z* 60.

The improvement obtained by replacing the monodimensional GC by GC × GC was considerable in the case of TOF-MS detection also, as illustrated by the high match factors generally obtained during identification. The results demonstrated that the two utilized sampling techniques are complementary; SPE gave more detailed results on the polar part of the sample, while SPME provided an overview of its headspace (including nonpolar analytes).

Furthermore, GC × GC coupled with a time-of-flight mass spectrometer (GC × GC–TOF-MS) has also been applied to investigate the dairy and nondairy sour-cream flavors [37]. The extracts were obtained by SAFE and cold-finger (CF) distillation, and were analyzed on a nonpolar–midpolar column set. As expected, the authors demonstrated improved separation and identification, and more importantly, the ng/g-level quantification was more reliably performed. Peak assignment was based on the peak table generated by the GC–TOF-MS software after data processing and the additional use of well-ordered patterns in the ^{2}D-plane; moreover, information from ^{2}D retention times helped in the identification of the unknowns. In Figure 22.2, full-scan GC × GC chromatograms of the nondairy (Figure 22.2A and B) and dairy (Figure 22.2C) sour-cream extracts are represented as color plots in the elution ranges from *n*-octane to *n*-octadecane.

22.3.1.4 Odor-Activity Assessment by Means of Gas Chromatography-Olfactometry

The description of a gas chromatograph modified for sniffing its effluent to determine the volatile odor activity, was first published in 1964 by Fuller et al. [38]. The introduction and diffusion of GC-O proved to be vital for the development in the research field of odor-active compounds, providing valuable information on the chromatogram regions that required attention and resources. GC-O is a unique analytical technique which associates the resolution power of capillary GC with the selectivity and sensitivity of the human nose. Consequently, GC-O provides not only an instrumental, but also a sensorial analysis. The latter is defined as a science responsible for the quantification of the human responses to the stimuli perceived by the senses of sight, smell, taste, touch, and audition [39,40]. In addition, it is worth to highlight that the verbal expression of quality is of great importance in sensorial analysis, as well as in GC-O, to achieve normalized responses from the human perception. As a consequence, the development of glossaries of olfactive descriptors adequate for each food matrix is of great importance, and most commonly, the panels create their own list to describe the notes of the product under investigation. However, it is important to outline that in GC-O analysis, synergistic or suppressive effects of different odorants present in a dairy food matrix are not considered, and the sample preparation steps may deprive some of the characteristics of the real matrix. In general, the compounds detected as odor-active in GC-O are most likely to be significant. However, the investigated extract could be too concentrated and

© 2011 by Taylor and Francis Group, LLC

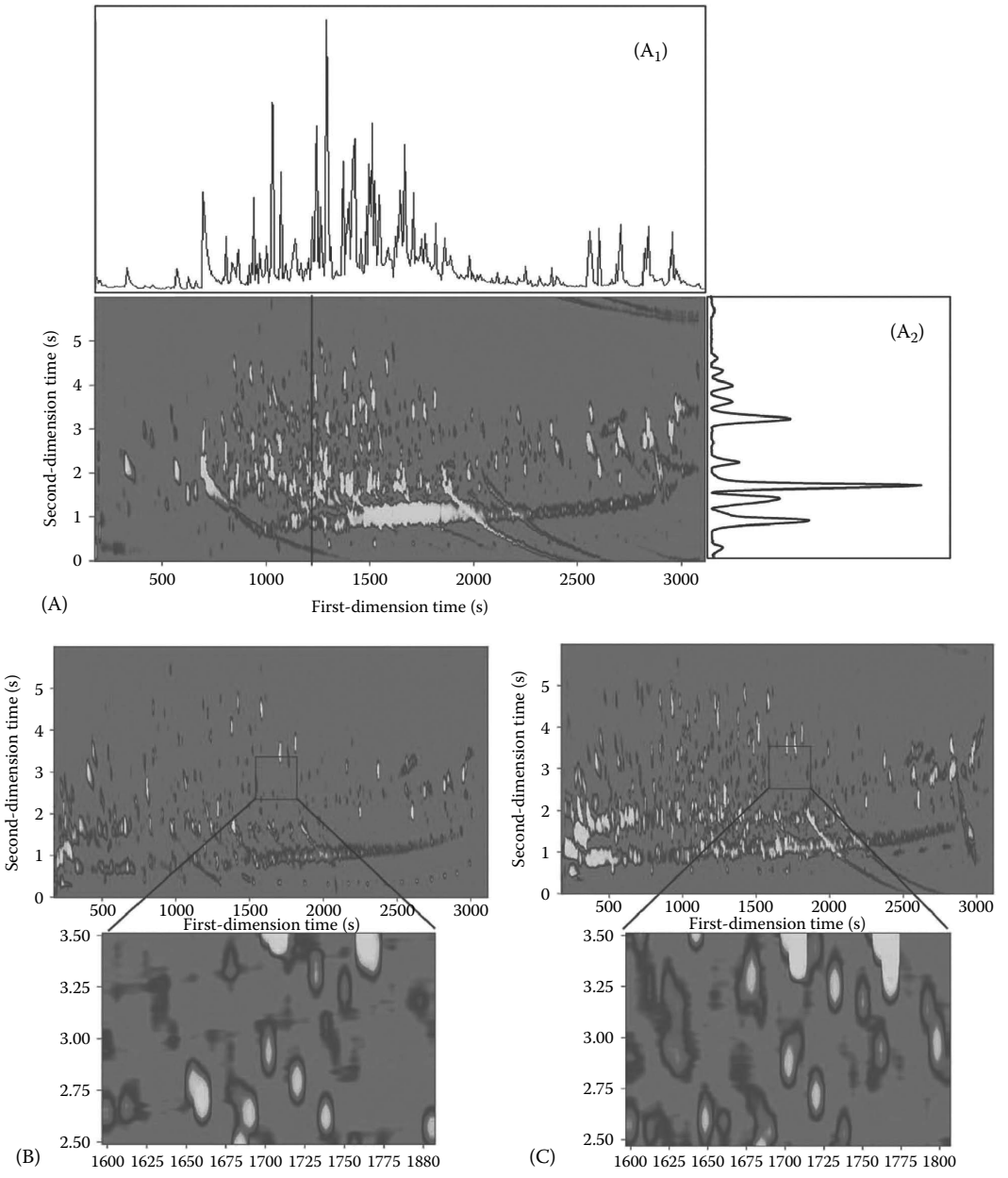


Figure 22.2 GC × GC–TOF-MS chromatograms of sour-cream extracts. (A) CF distillation of a nondairy sour-cream extract with its reconstructed ^{1}D chromatogram (A_1) and the intersection across the second dimension of the plane of the marked region (A_2); (B) SAFE of the same nondairy sour-cream extract, and (C) SAFE of a dairy sour-cream extract. (Reprinted from Adahchour, M. et al., *J. Chromatogr. A*, 1019, 157, 2003. With permission.)

© 2011 by Taylor and Francis Group, LLC

hence, may present odor-active compounds in GC-O, but not in the dairy food, or the compounds might not be odor-active in GC-O owing to an insufficient concentration of the extract, but still contribute to the odor of the food matrix.

The training of panelists, more precisely of the human noses, and the data-handling methods began to include some of the practices commonly used in sensory testing. Over the last decades, GC-O has been largely used in combination with sophisticated olfactometric methods that were developed to collect and process the obtained data, and thus, to estimate the sensory contribution of a single odor-active compound. The GC-O methods are commonly classified into four categories: dilution, time-intensity, detection-frequency, and posterior-intensity methods.

Dilution analysis, the most-commonly applied method, is based on the successive dilutions of an aroma extract, until no odor is perceived by the panelists. The dilution series of the original aroma extract are evaluated and the key odorants are ranked in the order of potency. This procedure, usually performed by a reduced number of assessors, is mainly represented by combined hedonic aroma response method (CHARM) [41], developed by Acree et al., and aroma extraction dilution analysis (AEDA), first presented by Ullrich and Grosch [42].

The dilution method CHARM has been applied to determine the key odorants of ovine milk, derived from animals subjected to distinct diets (natural pasture, grass meadow, and mixed grain rations), investigating the effects of the diet on milk flavor [43]. The key-odor notes were observed to be similar for all the three samples, although differing in intensity. Ethyl butanoate and ethyl hexanoate were reported as potent for all the three diet types, while heptanal, octanal, and nonanal were more relevant for the milk obtained after the mixed grain ration diet. Compounds, such as 1-octen-3-ol, dimethylsulfone, and indole presented higher odor potency in the milk produced by the ewes fed with natural pasture and grass meadow.

The AEDA is the most frequently reported GC-O method applied to dairy flavor investigations. An interesting application was carried out on the Cheddar cheese, one of the best studied varieties, analyzed for the first time by means of GC-O in 1995, when Christensen and Reineccius performed an investigation on the odor-impact compounds present in 3-year-old cheeses [44]. The components that presented a higher impact, based on their dilution factor were ethyl acetate, 2-methylbutanal, 3-methylbutanal, 2,3-butanedione, α-pinene, ethyl butyrate, ethyl caproate, 1-octen-3-one, acetic acid, and methional, followed by several acids. However, it is important to outline that according to the authors, AEDA was not the optimal method as it did not enable a complete determination of the volatile odor fraction that would include the assessment of hydrogen sulfide, acetaldehyde, and methanethiol.

Another interesting research applying AEDA was performed on the volatile aroma fraction of the two sharp Cheddar cheeses of British Farmhouse origin [45]. The identification of some specific flavor notes was successfully carried out, and *p*-cresol was characterized to be chiefly responsible for the so-called cow-resembling and phenolic note, whereas an intense soil-like odor could be related to 2-isopropyl-3-methoxypyrazine. At a much lower odor intensity, 2-isobutyl-3-methoxypyrazine contributed to the earthy, bell pepper-like odor elicited by the samples. It must be noted that the concentrations of *p*-cresol and 2-isopropyl-3-methoxypyrazine were lower in the core than in the rind of the same wedge of cheese.

Furthermore, the time-intensity methods, such as OSME (Greek word for odor), are based on the immediate recording of the intensity as a function of time by moving the cursor of a variable resistor [46]. The OSME has been successfully applied to the analysis of mature Cheddar cheese flavor buccal headspace extracts, for the determination of its odor profile during human consumption [16]. The BHA extract, briefly described in Section 22.2, was compared with that obtained by vacuum distillation by means of OSME-based GC-MS-O investigations. However,

© 2011 by Taylor and Francis Group, LLC

it is worth to outline that vacuum distillation extracts do not necessarily represent the compounds that are perceived by a person during the eating process, while BHA extracts comprise volatile compounds that are displaced during the mastication of a food matrix, in concentration ratios that stimulate the olfactory epithelium. The GC-MS-O analyses and OSME, performed by two panelists, enabled the determination of the contribution of individual compounds to the aroma of the mature Cheddar cheese; the time-intensity data were then analyzed using PCA, providing a so-called principal aromagram. The analytical column's effluent was split to the MS and sniffing port at a ratio of 1:20, respectively, and the time-intensity data were recorded on a module using a 100 mm unstructured line scale and a modified computer mouse that incorporated a resistance to movement. The modified mouse allowed the assessors to relate the perceived odor intensity to the physical stimulus of hand pressure. According to the principal aromagram intensity measurement, representing the weighted average of each assessor's time-intensity data, the BHA extract was characterized mainly by ethyl hexanoate, ethyl butyrate, methional, ethyl hexanoate, octanal, and dimethyl trisulfide. Furthermore, 11 unknown compounds were considered relevant to the odor of the matrix, giving an earthy, garlic-like, and raw mushroom contribution to the odor profile. On the other hand, by means of vacuum distillation, a near-complete volatile extract was obtained, which could be distinguished from the BHA extracts by the presence of low vapor pressure odor-active volatile compounds. The odor-potency of this fraction was mainly characterized by the presence of methional, ethyl butyrate, ethyl hexanoate, dimethyl trisulfide, and 3-methylbutanal. The contribution of the earthy note was likewise representative and also of a musty one.

Another approach, the detection frequency method [47,48], used the number of evaluators detecting an odor-active compound in the GC effluent as a measure of its intensity. This GC-O method was performed with a panel of numerous and untrained evaluators; 8–10 assessors were considered as a good agreement between low variation of the results and the analysis time. It must be added that the results attained were not based on real intensities, and were limited by the scale of measurement. The GC-O associated with the detection frequency method was applied in the investigation of yogurt flavor [49]. To extract the delicate and low intense flavor of yogurt, mild sample isolation methods were applied, such as combined SHS and DHS, and preparative SDE under vacuum. Out of the 91 compounds identified by means of GC/MS, 21 had relevant impact on the odor of the sample. These compounds were recorded by pressing a button during the whole sensory impression and the square signal was recorded by the software; each peak's odor description was registered on a tape. The obtained aromagrams were then averaged allowing the odor profile comparisons, and as peak intensities were related to the frequencies of the odor detection, the nasal impact frequency (NIF) profile was subsequently established. In the NIF approach, no intensity measurement was performed, and consequently, peak intensities were not related to the compound's odor intensity, but to their detection frequency. Commonly, peak heights and areas were defined as NIF and surface of NIF (SNIF), respectively. Each panelist participated in $1/n$ of the final results (n stands for the number of panelists); if NIF was 100%, all n panelists detected the odorant [48]. One of these compounds, 1-nonen-3-one, was identified by GC/MS/MS for the first time in a food flavor. Its extremely low odor detection threshold of 8 pg/kg, makes it one of the most potent compounds identified in flavors and off-flavors. In addition, the authors analyzed a milk mixture composed of skimmed milk powder and pasteurized full fat milk, to identify whether flavor compounds are already present in the milk or are generated by the strains. The NIF profiles of the yogurt and milk extracts are illustrated in Figures 22.3 and 22.4, respectively. By considering that the peak areas take into account the possible minor variations of the retention for each of the eight assessors, the SNIF values were used to compare the yogurt and milk

© 2011 by Taylor and Francis Group, LLC

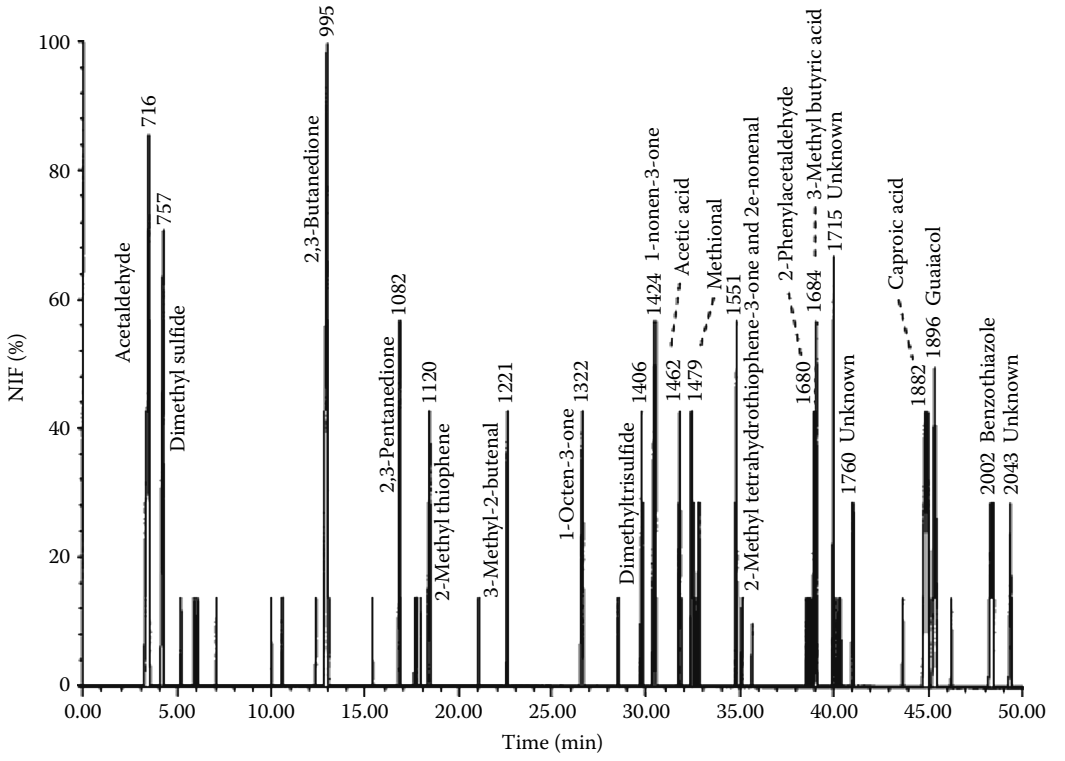


Figure 22.3 NIF profile of the headspace of a yogurt sample (retention indices are showed at the peak apex). (Reprinted from Ott, A. et al., *J. Agric. Food Chem.*, 45, 850, 1997. With permission.)

aromagrams. It could be observed that the SNIF values of several compounds, such as acetaldehyde, 2,3-butanedione, 2,3-pentanedione, methional, 2-methyltetrahydrothiophene-3-one, and (2*E*)-nonenal, were greatly increased by the fermentation step.

Another GC-O technique, the posterior intensity method [50], proposes the measurement of a compound's odor intensity and its posterior scoring on a previously determined scale. This posterior registration of the perceived intensity may cause a considerable variance among the assessors. The attained results may generally be well correlated with the results of the detection frequency method, and to a lesser extent, with dilution methods.

The posterior intensity method was applied for the investigation of a characteristic nutty flavor of some Cheddar cheeses, along with AEDA [51]. The solvent extracts and DHS sampling of young and aged, nutty and not nutty, cheese models were compared. The solvent extracts were analyzed on the capillary columns of distinct polarities, while the DHS samples were examined solely on a polar column. The DHS recovery technique enabled an optimized investigation, revealing that the Strecker aldehydes, such as 2-methylpropanal, 2-methylbutanal, and 3-methylbutanal, imparted a nutty note to that matrix, especially in aged cheeses. On the other hand, in Swiss-type cheese, also classified as a hard cheese, propionic acid was the key compound considered to be responsible for the nutty note [52].

With respect to AEDA, another method known as the aroma extract concentration analysis (AECA) [53], was developed and applied to Camembert cheese analysis [54]. Prior to AEDA, the

© 2011 by Taylor and Francis Group, LLC

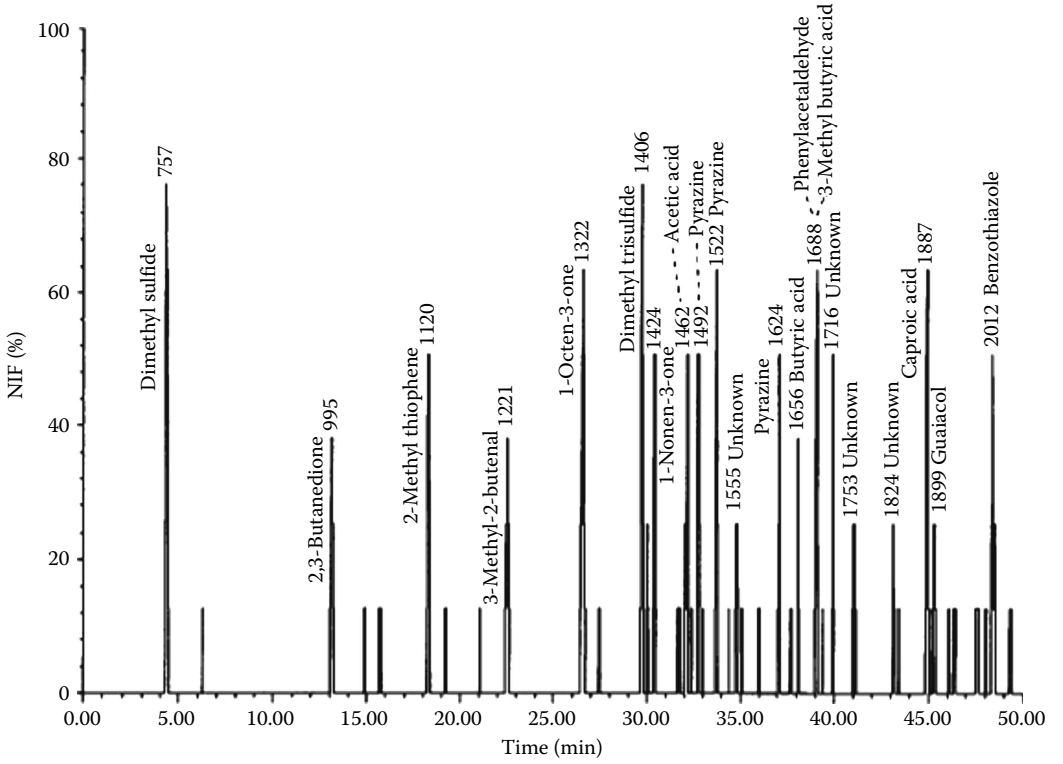


Figure 22.4 NIF profile of the headspace of a milk sample (retention indices are showed at the peak apex). (Reprinted from Ott, A. et al., *J. Agric. Food Chem.*, 45, 850, 1997. With permission.)

extract is concentrated by distillation procedures, possibly leading to the loss of volatiles, which may represent a shortcoming of the method. On the other hand, in the AECA, the original volatile extract is first analyzed with GC-O analysis, which was then concentrated stepwise by distilling off the solvent, and subsequently, after each step, an aliquot was analyzed. The volatiles 2,3-butanedione, 1-octen-3-one, 1-octen-3-ol, β-phenethyl acetate, 2-undecanone, δ-decalactone, butyric acid, and isovaleric acid were found to be fundamental for Camembert aroma. An interesting aspect was the coelution of 1-octen-3-one and 1-octen-3-ol on a nonpolar stationary phase, which could be separated on a polar phase and analyzed by AECA. The authors assumed that the odor intensity of 1-octen-3-ol might have been enhanced by the corresponding ketone, 1-octen-3-one, both eliciting a mushroom-like note. In addition, further GC-O analyses carried out on the SHS sample suggested that methanethiol and dimethyl sulfide might also play a significant role. The mushroom, floral, and garlic notes in Camembert aroma, as described by Dumont et al. [55], were related to 1-octen-3-ol, β-phenethyl acetate, and dimethyl sulfide, respectively.

A further method, the dynamic headspace dilution assay (DHDA), was applied by Zehentbauer and Reineccius on a mild Cheddar cheese variety [56]. Dilution was made through a stepwise decrease of the purge time, starting with 30 min, which was equivalent to a flavor dilution (FD) factor of 1, and ending with 20 s, corresponding to FD 64. Each dilution was sniffed by a single evaluator on three capillary columns coated with distinct stationary phases, and the identified odorants were then reported on at least two stationary phases. In addition to the compounds previously identified by means of GC-O analysis of the HS samples applying AEDA [57], namely,

© 2011 by Taylor and Francis Group, LLC

methional, 2(5)-ethyl-5(2)-methyl-4-hydroxy-3(2*H*)-furanone (homofuraneol), diacethyl, acetic acid, and butyric acid, by means of DHDA, other key aroma components were identified, such as (*Z*)-4-heptenal, 2-acetyl-1-pyrroline, dimethyl trisulfide, 1-octen-3-one, (*Z*)-1,5-octadiene-3-one, and (*E*)- and (*Z*)-2-nonenal. Moreover, as supported by other authors [16,58], it was pointed out that single volatiles eliciting characteristic Cheddar cheese notes were not identified. Similarly, for the other cheese types, a characteristic odor was defined by the so-called component balance theory [58], based on a wide range of parameters, such as cheese age, microflora, biochemistry, as well as odor extraction methods.

The choice of the GC-O method is extremely important for the correct characterization of a matrix, as the application of different methods to an identical real sample can distinctly select and rank the odor-active compounds according to their odor potency and/or intensity. Commonly, detection frequency and posterior intensity methods provide similar odor intensity/concentration relationships, while dilution analyses investigate and attribute odor potencies.

An example of the application of the two methods, OSME and AEDA, was reported to estimate the most potent odors of DHS samples [59]. The latter was carried out on both polar and nonpolar stationary phases, while the former was performed only on a polar stationary phase. Acetaldehyde, 2-methylpropanal, 3-methylbutanal, ethyl hexanoate, dimethyl trisulfide, and methional were identified as intense odorants by OSME, and were found to possess the highest FD values by AEDA. In addition, the latter method also enabled the determination of further potent odorants, such as ethyl butyrate, diacethyl, DMHF, 2-methylbutanal, 2,6-dimethylpyrazine, 2-heptanone, and 2,4-hexadienal.

An enormous number of dairy food matrices have already been studied by means of GC-O, and have been briefly reviewed by Friedrich and Acree in 1998 [9]. In addition, Curioni and Bosset published an overview focused on GC-O analysis of various types of cheeses [60].

22.3.1.5 Dairy Flavor Fingerprint Acquisition through Mass Spectrometry

It has been demonstrated that the rapid analysis of the volatile fraction of food products by MS is a valuable approach to classify or predict quality features, and nonseparative methods, such as SPME-MS, DHS-MS, and SHS-MS, are useful in the acquisition of a sample's fingerprint.

In 1999, Marsili proposed the use of SPME–MS associated with multivariate analysis (SPME–MS-MVA) for the investigation of off-flavors in milk [61]. The system, also defined as the mass detection-based electronic nose, was composed of a GC/MS instrument, in which the GC injection port was used for the thermal desorption of the 75 μm Carboxen/PDMS SPME fiber, and instead of an analytical column, an uncoated fused silica line (1 m × 0.25 mm i.d.), kept at 50°C, was used as a transfer line to the MS system. Mass fragmentation data derived from the unresolved milk volatile components were subjected to MVA. The PCA based on SPME–MS-MVA permitted the classification of the samples by the origin of off-flavors, and thus, the differentiation of the control reduced-fat milk (2% butterfat content) samples from those affected by light, heat, copper, and microbial contamination. The shelf-life prediction of the pasteurized and homogenized reduced-fat milk and whole-fat chocolate milk was also carried out by SPME–MS-MVA [62]. The SPME, using a Carboxen/PDMS fiber, enabled the extraction of volatile bacterial metabolites from the matrices, and both the milk types were sampled six times over a period of 7 months. Mass fragmentation profiles from the unresolved milk volatile components were normalized to the intensity of the internal standard mass peak (chlorobenzene, *m/z* 112) and subjected to MVA. By using prediction models based on PLS regression of mass intensity lists, the samples' shelf-life

© 2011 by Taylor and Francis Group, LLC

prediction was established to be of about 1 day ($r > 0.98$). Moreover, the use of two-dimensional PCA plots also made it possible to classify unpalatable samples affected by microbial as well as nonmicrobial sources, such as copper or sanitizer contaminations.

A similar approach was applied for the characterization of cheeses [63], but by using a narrower transfer line, i.e., 1 m × 0.10 mm i.d., heated to 210°C. Five samples of Camembert at different stages of ripening were investigated. For data analysis, the mass fragments of each spectrum, ranging from 45 to 150 amu, were considered as potential descriptors of the composition of the headspace of the cheeses. In Figure 22.5a, the SPME–GC/MS chromatographic profile of one of the samples is presented, while in Figure 22.5b, the reconstituted average spectrum obtained by SPME-MS is shown; fragments of *m/z* 47, 62, 79, and 94 are the characteristic of compounds, such as methanethiol, dimethyl sulfide, dimethyl disulfide, and dimethyl trisulfide, respectively. The batches of investigated cheeses were then classified on the basis of a limited number of mass fragments selected by stepwise discriminative analysis. According to the authors, SPME-MS provided a rapid quality control with minimized thermal, mechanical, and chemical modifications of the matrix, thereby, reducing the risk of artifact formation.

Proton-transfer reaction-mass spectrometry (PTR-MS) is a relatively new technique, which allows fast and accurate determination of the concentration of volatile organic compounds down to the ppt range [64]. The PTR-MS was used along with GC-O to deduce the volatile profile of three Grana cheeses: Grana Padano, Parmigiano Reggiano, and Grana Trentino [65]. For GC-O analyses, the volatile compounds were extracted by DHS, while for PTR-MS, the headspace formed over the cheese was directly assessed. The PTR-MS analysis revealed that 50 masses (parent and fragment ions) gave a significant contribution, with at least 60 compounds being tentatively identified. On the other hand, GC-O analysis characterized 11–14 compounds being responsible for the basic odor profile of Grana cheeses, revealing ethyl butanoate, 2-heptanone, and ethyl hexanoate, all eliciting fruity notes, as the major contributors to the cheeses flavor. Other low-odor threshold compounds, such as methional and 1-octen-3-one

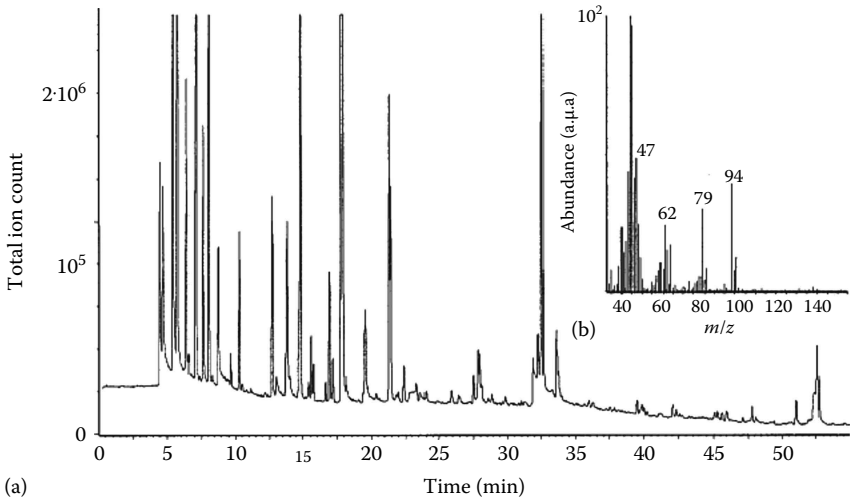


Figure 22.5 SPME-GC/MS chromatogram of a Camembert cheese sample (extraction by Carboxen/PDMS fiber in the headspace at 20°C for 10 min) (a), and a reconstitution of an average spectrum obtained by SPME-MS (0–55 min) (b). (Reprinted from Pérès, C. et al., *Anal. Chem.*, 73, 1030, 2001. With permission.)

© 2011 by Taylor and Francis Group, LLC

were indicated as contributors to the characteristic flavor of the sample, although not being detected by the FID, but by PTR-MS. Thus, the successful use of GC-O to determine the odor-active compounds of the cheeses' headspace was confirmed, while PTR-MS presented to be a useful tool for the quantification of odor-active and nonactive compounds present in the cheeses' volatile fraction.

22.3.1.6 Electronic Nose and Tongue in Dairy Flavor Analysis

It is well-known that the flavor of dairy food is considered as an indicator of its quality and product conformity, though flavor quality-control assessments in food industries are difficult, owing to the lack of reliable odor-assessing instruments and the difficulty in using sensory panels for the continuous monitoring of a product's odor. Since 1991, research has been conducted to develop technologies that could detect and recognize odors and flavors using the so-called artificial senses, whose function is to reproduce human senses using sensor arrays and pattern-recognition systems. The first electronic system created to measure odors was the electronic nose (e-nose), whose name was derived from the fact that its main task is to mimic the human olfaction. The system is based on the combination of a gas-sensor array with broad and partly overlapping selectivity patterns and multivariate data analysis (MVDA). Nonseparative mechanisms are used to represent a perceived odor or flavor as a global fingerprint. A further system widely applied in food industries is the electronic tongue (e-tongue or taste sensor), based on the concepts similar to the e-nose, but in aqueous solution. While e-noses are related to olfaction, e-tongues are related to the sense of taste.

Moreover, it is worthwhile to point out that several e-nose sensors have already been reported in literature, such as metal oxide semiconductors (MOS), conducting polymers (CP), quartz crystal microbalance (QCM), surface acoustic wave (SAW), and field effect transistors (MOSFET) [66]. The recently developed e-nose techniques also use MS or ultrafast GC as the detection systems. The MS-based e-noses have already been mentioned in Section 22.3.1.5. On the other hand, e-tongues are generally based on potentiometry or voltammetry [67].

The utilization of e-noses have been reported in the investigations of several aspects of dairy flavor, such as for the early detection of spoilage bacteria and yeast in milk-based media using a system composed of 14 CP sensors [68], and also for the discrimination of three different resistant bacteria, occurring isolated or as a mixture of all the three strains cultured in milk utilizing an e-nose consisting of 10 MOSFET, 5 MOS, and an infrared-based CO_2 sensor [69]. An e-nose system, composed of 12 MOS sensors, has also been implemented to monitor flavor changes related to the maturation of Danish blue cheeses [70]. Though it is worth to highlight that the ripening process could be successfully monitored, this system presented some limitations in the determination of the cheeses' maturity stage owing to the similar flavor profile observed for 2- and 4-week-old cheeses. A similar investigation was performed by the same research group, but using a system equipped with 14 CP sensors [71]. In the latter work, the authors were able to classify the ripening age of the products from different units, as well as different products from the same unit. Furthermore, the infant milk-powder formulas, English Cheddar cheese, pasteurized whole milk, and butter were also subjected to e-nose studies [72]. The use of e-noses in dairy flavor analysis has been extensively reviewed by Ampuero and Bosset in 2003 [73].

The utilization of e-tongues in diary products analysis is not often reported, mainly owing to the harsh conditions of the industrial processes, specially cleaning procedures and the large material restrictions in the dairy industry. Taking the latter aspect into consideration, Winquist et al. [67] described a voltammetric e-tongue, specially designed to monitor the sources of raw milk coming to an industrial dairy process, as well as the cleaning process. The e-tongue consisted

© 2011 by Taylor and Francis Group, LLC

of four working electrodes made of gold, platinum, rhodium, and stainless steel, embedded in polyetheretherketone (PEEK™) and mounted in a housing of stainless steel, which was inserted in the process line for direct online measurements. An e-tongue based on pulsed voltammetry was also applied in the study of milk-quality deterioration owing to microbial growth during storage at room temperature [74]. The system consisted of a reference, auxiliary, and working electrodes; the latter was represented by five wires of different metals (gold, iridium, palladium, platinum, and rhodium). The data obtained were examined with PCA and the deterioration process could be clearly observed; moreover, prediction models could be prepared by using projections to latent structure and artificial neural networks.

22.3.2 Sensorial Dairy Flavor Analysis

As previously defined in Section 22.3.1.4, sensorial analysis uses panels of human subjects to evaluate a material or product. In general, sensory testing may be divided into two categories: hedonic and analytical tests. Hedonic tests are designed to assess the effect caused by the material or product under investigation, such as pleasant or unpleasant, determining the consumers' preferences. Therefore, these tests are carried out using a large number of untrained panelists, selected to be the representative of the population as a whole. On the other hand, analytical tests preferentially use smaller panels composed of specially selected and trained evaluators, and can be divided into discriminative and descriptive tests. The former are designated to determine whether a perceptible sensory difference exists between the samples as well as to find the thresholds and sensitivity, while the latter are performed to describe a material or product in terms of a number of predetermined descriptors.

All the methods were carried out using an extensively trained panel to ensure that the descriptors in use are well understood and the quantitative score of the samples against different descriptors is reliable. The distinct classes of analytical tests aim to address different questions, and in all cases, it is necessary to carefully select the individual panel members, ensuring appropriate sensitivity to a wide range of odorant types and normalized responses.

22.3.2.1 Odor-Activity Value Determination

The screening of significant odorants in food samples has not only been extensively studied by means of GC-O dilution methods, but also through the odor-activity value (OAV) concept. As previously described in Section 22.3.1.4, in dilution methods, the identified key odorants are ranked in the order of potency, and the highest dilution at which a substance is sniffed is represented by its FD value. The latter value is considered as proportional to the OAV evaluated in air [75]. Both the methodologies are applied for the determination of the flavor compounds that most likely contribute to the overall odor of a food.

In 1957, Patton and Josephson first proposed an estimation of the importance of a flavor chemical in a food, based on the ratio of its concentration in that food to its threshold concentration in that same matrix [76]. Based on this approach, in 1963, Rothe and Thomas derived the OAVs to better correlate the concentration of an odorant with its detection threshold value [77], defined as the lowest concentration or intensity that is perceived by the panelist [75]. Some flavor chemicals may present an increased intensity in odor activity according to a proportional increment of their concentration, while with regard to others, the change in intensity may be the opposite or just less marked. The theoretical intensity of an odorant under any specific set of conditions could be roughly expressed in terms of its OAV, also denoted as odor value, odor unit, flavor unit,

© 2011 by Taylor and Francis Group, LLC

and aroma value. However, the difficult and time-consuming determination of threshold values, which vary among and within the panelists [78], caused controversies related to the use of OAVs as indicators of the percent contribution to the overall intensity of a sample.

In addition, the synergistic or suppressive effects of different odorants in a food matrix are not considered in OAV determinations and GC-O analysis. The sample preparation steps may deprive the real food matrix of some of its characteristics. As previously mentioned, the compounds detected as odor-active by means of GC-O are most likely to be significant. However, the investigated extract may be too concentrated and hence, may present odor-active compounds in GC-O, but not in the food sample. On the contrary, it is also true that some compounds might not be odor-active in GC-O owing to an insufficient concentration in the extract, but may still contribute to the overall odor of the food matrix.

Recombined model systems are commonly applied in dairy flavor investigations to study and evaluate sample's characteristics or to confirm the instrumental results. In this respect, model systems for a specific food sample are commonly prepared based on the combination of previously achieved AEDA or CHARM values, and/or OAVs.

Odorants showing higher values are used to formulate the recombined model, which is then compared with the real food product for similarity or difference. The preparation of such models is simple for liquid food matrices, attaining a homogeneous blend of odorants, and satisfactory results were observed in the study of sour-cream butter flavor [78]. However, difficulties arise in the preparation of models for solid foods, as it is not simple to simulate the composition and structure of the nonvolatile fraction of the food and imitate their odorant's distribution. We can overcome this limitation by using suitable inert alternative bases, such as cellulose or sunflower oil.

In omission experiments, on the other hand, a recombined model system is prepared, in which one or more odorants are omitted. In this experiment, the panelists are asked to perform discriminative tests to compare the reduced model with the complete one, and indicate the perceived sensorial differences [79].

Milo and Reineccius [57] investigated and quantified the chemicals responsible for the flavor of regular-fat and low-fat Cheddar cheeses through GC-O analysis of their SHS. The gas chromatograph was connected to a purge and trap system, and equipped with a nonpolar column. The AEDA was also carried out on a cheese-flavor fraction isolated by high-vacuum distillation. The latter analyses were performed on three stationary phases of distinct polarities. Two panelists performed AEDA, and subsequently, the OAVs of the odorants described as potent were calculated on the basis of quantitative data and on sensory thresholds in oil and water. The authors suggested that acetic acid, butyric acid, methional, diacethyl, and homofuraneol were primarily responsible for the pleasant mild aroma of Cheddar cheese. In addition, highly volatile sulfur compounds, such as methanethiol and dimethyl sulfide, contributed significantly to the flavor. Furthermore, the meaty, brothy off-flavor of low-fat Cheddar was related to the high concentrations of methional, DMHF, and mainly, homofuraneol. The higher water content in low-fat cheese, combined with a possible increased microbial activity, was assumed to be the reason for the elevated concentrations of the latter compounds. However, a combination of methanethiol and decanoic acid or butanoic acid in all cheeses gave a better correlation with Cheddar flavor than methanethiol alone [80].

22.3.2.2 Analytical Sensory Tests

Analytical sensory tests, either discriminative or descriptive, are widely used in dairy flavor analysis. By definition, discriminative tests are applied to determine whether a perceptible sensory difference exists among the samples, and also to establish the thresholds and sensitivity. These tests

© 2011 by Taylor and Francis Group, LLC

are classified as paired comparison (or duo test), triangle, and duo-trio test. On the other hand, in descriptive tests, the lists of descriptors are adopted, which can be quite extensive, and therefore, a more accurate training of the panel is required to ensure that the descriptions are well understood, and the samples are reliably and quantitatively scored. The descriptive tests can be divided into flavor profile method (FPM), quantitative descriptive analysis (QDA), and the Spectrum™ method.

The simplest type of discriminative test, the paired comparison test, has been conduced in the evaluation of vanilla-flavored ice creams, to establish a relationship between perceived difference and expressed preference [81]. In this test, two ice-cream samples were presented to the evaluators and asked whether they preferred one or the other, or did not have any preference. The results were tentatively used to establish when a perceived difference might start translating into a change with regard to the acceptability of the original product, and possibly predict the consumers' perceptions from an in-house semitrained or trained panel, reducing the time duration and the relatively high-cost consumer testing.

Triangle tests have been reported in the study of Camembert cheese flavor [82]. In triangle tests, the panelists assess three samples, two of which are identical, and are asked to select the odd sample. First, the Camembert cheese samples were screened to establish the flavor compounds, subdivided into groups, which contribute to the sample's odor and taste. Subsequently, the intensities of various combinations of the groups were determined in the triangle tests, to identify the groups that contributed to the flavor of Camembert. The three groups described as salty, monosodium glutamate-like, and bitter were rated as very strong, while the amino acids groups defined as sweet and bitter were not found to contribute to the cheese's taste. This test has also been applied to evaluate the effect of lipases on the flavor of ultra heat treatment (UHT) milk [83]. However, in this case, the panelists were asked not only to indicate the sample that differed from the rest, but also to indicate when a rancid flavor was present. The results showed that added lipase had a pronounced effect on the development of rancid flavor.

In the duo-trio tests, a standard sample was presented to the panel, to compare it with the two unknown samples; one of the unknowns being identical to the standard. The panelists were asked to identify which unknown matched the standard. This test has been used in the evaluation of Cottage cheese samples treated with 0.025%–0.20% of potassium sorbate against a standard sample of untreated Cottage cheese [84]. For shelf-life evaluations, the samples were stored at 4°C or 7°C. The minimum level of potassium sorbate detected by the panel was of 0.10%. With regard to the shelf-life of cheeses, the results suggest that concentrations of potassium sorbate of 0.05%–0.10% by weight can be used advantageously to increase the shelf-life of commercial Cottage cheese. These quantities of potassium sorbate retarded the growth of bacteria responsible for the fruity and putrid odors as well as slime in Cottage cheese at refrigeration temperatures, as well as bacteria capable of producing sourness and molds.

The descriptive tests, either FPM or QDA, used a carefully selected and extensively trained panel to eliminate biological variations between the individual panelists. The FPM was developed in the 1950s, and is the first published descriptive sensory technique. Later, in the 1970s, QDA and the Spectrum™ descriptive analysis method [40] were proposed. The latter methods differ from the FPM in that they were developed to use the measurements determined by individual panelists and generate a panel average. On the other hand, in the FPM, a group consensus profile is generated. Moreover, FPM generally uses fewer panelists than the other two methods.

The FPM and its many derivatives have been successfully applied to dairy food analysis, e.g., in the evaluation of the optimal level of *Lactobacillus bulgaricus* to be added to milk to produce a Swiss cheese with more intense flavors, considered as desirable by the panel [85]. In another study, FPM was used in the evaluation of fruit-flavored dairy products, such as strawberry-blended

© 2011 by Taylor and Francis Group, LLC

yogurts and apricot-flavored fresh cheeses [86]. The FPM was compared with a recently developed technique known as Flash profile [87], which is based on the combination of free-choice profiling and a comparative evaluation of the whole product set. Analyses were performed using a panel comprising 10 evaluators, extensively trained for the evaluation of fruit flavor in blended fruit yogurt for 25–80 h. Both the fruity flavored dairy products had their flavor profile slightly more discriminated by the Flash profile.

Amongst the most widely applied descriptive tests is QDA, considered as one of the most important tools to study a sample's flavor, appearance, and texture. An example worth mentioning is the descriptive flavor analysis of two different Ragusano cheeses (pasture-fed and total mixed ration-fed) [88]. The analyses were carried out by a panel composed of 12 evaluators, with a glossary of descriptors generated over several training sessions and a score scale ranging from 1 to 15. The panelists were asked to rate the relative intensities of four different classes of attributes (aroma, taste and chemesthetic, consistency, and mouth structure). All data were subjected to PCA, and the significant differences in the sensory and chemical analyses could be observed between the cheeses. A further noteworthy application of QDA was performed in correlation with the PTR-MS spectral fingerprint for the characterization of Grana Trentino cheeses [89]. QDA was performed by eight panelists, trained with a glossary of descriptors containing 30 attributes, though only 6 related to odors and 6 to flavors were taken into consideration during the analyses. QDA and PTR-MS data correlation was made through multivariate calibration capable of modeling and predicting the sensory intensity of many sensory attributes. In conclusion, it is indicated that the information contained in PTR-MS spectra is enough to foresee the value of several QDA attributes and the variability of the overall flavor profile. Moreover, the authors highlighted that the correlation between the chemical indication and sensory data is not a causality, as it is known that more than one volatile compound contribute to the overall perceived complex cheese flavor, and not every measured peak necessarily correspond to a sensory effect.

The other descriptive test, the Spectrum method, was applied to study the flavor of fresh Chevre-style goat cheese [90]. First, the sensory descriptive evaluation was carried out by seven trained panelists. The cheeses were 2 cm^2 cubes with three digit codes, and during evaluation, the panelists had free access to water and unsalted crackers. Flavor and taste intensities were scaled using a 10-point intensity scale, and each cheese sample was evaluated in duplicate. The model system sensory evaluation was then performed to investigate the impact of selected acidic compounds on waxy/animal note of Chevre-style goat cheeses. Based on GC-O and quantification data, hexanoic, octanoic, decanoic, 4-methyl octanoic, and 4-ethyl octanoic acids were selected for the model system analysis. In a first step, these compounds were screened in an unripened cheese system (4% milk fat cottage cheese), then hexanoic acid was added, contributing to a sour, sweaty odor, and was not considered further. On the other hand, octanoic, decanoic, 4-methyl octanoic, and 4-ethyl octanoic acids contributed to waxy, animal, and soapy notes, and were included in the subsequent flavor evaluations. Moreover, the panelists established that a combination of 4-methyl and 4-ethyl octanoic acids at 143 and 187 ppb, respectively, gave the highest similarity to goat cheese, with a 9.5 on the 10-point scale, and that the octanoic and decanoic acids probably contributed to the waxy, animal note as well, but to a lesser degree than the branched-chain fatty acids.

22.4 Characterization of Off-Flavors

As previously mentioned, the main sensory attributes to be considered in the assessment of a dairy product are appearance, flavor, and texture, and these may vary in relation to the presence or

© 2011 by Taylor and Francis Group, LLC

absence of predetermined defects. It is obvious, therefore, that the dairy industry has acquired a broad knowledge on sensory defects, including their causes and consequences.

Off-flavors are widely defined as an unpleasant odor or taste imparted to a food sample though internal deteriorative change, while taints are imparted through external sources [91]. GC-O is a valuable technique to exploit off-flavors. Rychlik and Bosset [92] applied AEDA to investigate the origin of a potato-like flavor defect that was being observed in the Swiss Gruyère cheese produced by a Swiss village factory. The typical odor of that well-studied hard cheese could be attributed to a series of compounds, such as 2-methylbutanal, 3-methylbutanal, methional, dimethyl trisulfide, phenylacetaldehyde, 2-ethyl-3,5-dimethylpyrazine, 2,3-diethyl-5-methylpyrazine, methanethiol, as well as a variety of acids. The weak potato-like off-flavor could be detected, but the responsible compound was not identified. In another work carried out by the same researchers, the origin of this flavor defect was further investigated [93]. Methanethiol that exhibited the highest OAV in the sample was considered as a possible contributor. Moreover, methional was shown to have a significant impact on the potato-like flavor of the Gruyère cheese investigated. In addition, it could be observed that methional enhances the sweaty odor of 2-methyl butyric acid, 3-methyl butyric acid, and butyric acid, and masks the malty odor of 2-methylbutanal and 3-methylbutanal. It is interesting to highlight that cheese loaves produced in that cheese factory were subjected to different ripening schemes to identify if the defect could be related to ripening conditions or brine application. Finally, the brine and the brine bath were replaced and the defect no longer occurred. In this case the defect, previously defined as an off-flavor, was observed to be a taint.

Another curious off-flavor was the floral, rosy note identified in Cheddar cheese [94], which can be classified as an unclean off-flavor. The GC-O technique along with AEDA was applied, using both the polar and nonpolar capillary columns, and phenylacetaldehyde and phenylacetic acid from the catabolism of aromatic amino acids were reported to be responsible for that undesired note. The latter has also been previously reported in Camembert cheese [54].

The development of off-flavors in butter is a well-studied topic. Badings [95] detected a fishy off-flavor in a cold-stored butter sample. The defect was attributed to the presence of 1-octen-3-one, (*Z*)-4-heptenal, (*E*,*Z*)-2,6-nonadienal, hexanal, and (*E*)-2-nonenal, which presented high OAVs. On the other hand, Swoboda and Peers [96] indicated (*Z*)-1,5-octadien-3-one, formed by copper-catalyzed oxidation of butterfat, as a key contributor to a metallic odor defect in stored butterfat. Moreover, phospholipids were suggested as precursors in the formation of this metallic off-flavor in butter [97]. With regard to buttermilk odor, its typical mild, sweet-buttery odor is not stable, and during storage, a metallic off-flavor may also be generated; though little is known about the compounds causing this defect. A comparison was made between the impact of odor-active compounds present in fresh, fermented sweet-cream buttermilk and sour-cream buttermilk, on the basis of AEDA results [98]. The latter sample presented a metallic odor note which was formed after a storage period of 4 days at 8°C. In the sweet-cream buttermilk sample, 13 compounds revealed to be key odor compounds, and out of these, nine appeared with significantly higher FD factors in the sour-cream buttermilk, and the increase in FD factors of (*E*,*Z*)-2,6-nonadienol and the epoxyaldehydes 4,5-epoxy-(E)-2-decenal and 4,5-epoxy-(E)-2-undecenal, was considered to be the cause of the metallic off-odor developed in sour-cream buttermilk.

Furthermore, Mounchilli et al. [99] investigated the flavor of five milk samples (four off-flavored and one of good flavor quality), extracting the volatiles by HS-SPME and analyzing by GC/MS and GC-O. The composition of all the samples revealed to be nearly identical, differing in the concentration levels; the profile of odor-active compounds of all the four off-flavored samples was identical to those of the good-quality milk. Olfactometric analyses supported the hypothesis that off-flavors were probably caused by the concentration differences of a common

© 2011 by Taylor and Francis Group, LLC

subset of compounds, rather than from the absence or presence of specific compounds. Further milk off-flavors worth mentioning are those caused by volatile fatty acids (VFAs) generated as metabolites by the growth of lipolytic psychrotrophic bacteria [61], and the fruity off-flavor related to ppm-level concentrations of ethyl butyrate and ethyl hexanoate [100].

It must be noted that owing to the wide variety of substances belonging to several chemical classes, fresh milk flavor is an effective vehicle for off-flavors. The lability of some of the components triggers the immediate generation of flavor compounds by hydrolysis and oxidation, and also by enzymatic and microbial activities [101].

22.5 General Considerations on Dairy Flavor

As described in this chapter, numerous methodologies may be applied to dairy flavor investigation. Many isolation techniques have been developed to yield a product that is representative of the sample, promoting quality improvement of the obtained flavor profiles.

Several instrumental techniques may be utilized, and particularly, GC has evolved into a dominant analysis method providing the greatest resolving power for most of the dairy volatiles. The introduction of GC/MS technique that enables the characterization of structural compounds, and GC-O that permits the differentiation of a multitude of volatiles into odor- and nonodor-active ones, also marked a real turning point in the study of these volatile molecules. The application of MS to dairy food also contributed greatly towards the progress of the knowledge on those flavors being applied for fingerprint acquisition or as MS-based e-noses. Electronic sensors, such as e-noses and e-tongues, utilized for quality-control purposes also enabled the determination of sensory attributes associated with processing variables.

The application of sensorial analysis tests to dairy matrices also represents a breakthrough in the dairy flavor research, acting as a powerful tool for understanding the appearance, flavor, and texture attributes of dairy products, and capable of guiding the consumer's preference.

Moreover, the continuous need to understand the flavor developments owing to heat treatments, storage modalities, fermentation processes, hydrolysis and oxidation reactions, as well as enzymatic and microbial activities, has triggered the analytical and sensorial investigations of dairy matrices.

References

1. Laing, D. G. and Jinks, A., Flavour perception mechanisms, *Trends Food Sci. Technol.*, 7, 387, 1996.
2. Firestein, S., Electrical signals in olfactory transduction, *Curr. Opin. Neurobiol.*, 2, 444, 1992.
3. Firestein, S., How the olfactory system makes sense of scents, *Nature*, 413, 211, 2001.
4. Malnic, B., Hirono, J., and Sato, T., Combinatorial receptor codes for odors, *Cell*, 96, 713, 1999.
5. van Ruth, S. M., Methods for gas chromatography-olfactometry: A review, *Biomol. Eng.*, 17, 121, 2001.
6. Grosch, W., Determination of potent odourants in foods by aroma extract dilution analysis (AEDA) and calculation of odour activity values (OAVs), *Flavour Fragr. J.*, 9, 147, 1994.
7. Maarse, H. and Visscher, C. A., *Volatile Compounds in Food. Qualitative and Quantitative Data*, 6th edn., Central Institute for Nutrition and Food Research TNO-CIVO, Zeist, 1989.
8. Mariaca, R. and Bosset, J., Instrumental analysis of volatile (flavour) compounds in milk and dairy products, *Lait*, 77, 13, 1997.
9. Friedrich, J. E. and Acree, T. E., Gas chromatography olfactometry (GC/O) of dairy products, *Int. Dairy J.*, 8, 235, 1998.
10. Cronin, D. A., Techniques of analysis of flavours, in *Food Flavours. Part A. Introduction*, Morton, I. D. and MacLeod, A. J., Eds., Elsevier, Amsterdam, 1982, pp. 15–48.

© 2011 by Taylor and Francis Group, LLC

11. Imhof, R. and Bosset, J. O., Comparison of two systems for sample preparation and injection by dynamic headspace GC analysis, *J. High Resol. Chromatogr.*, 14, 621, 1991.
12. Urbach, G., Stark, W., and Forss, D. A., Volatile compounds in butter oil. II. Flavour and flavour thresholds of lactones, fatty acids, phenols, indole and skatole in deodorized synthetic butter, *J. Dairy Res.*, 39, 35, 1972.
13. Badertscher, R., Liniger, A., and Steiger, G., Bestimmung der flüchtigen Fettsäuren in Käse aus dem Wasswrdampfdestillat mit "Headspace-GC/FID", *FAM Info*, 272w, 1, 1993.
14. Deibler, K. D., Acree, T. E., and Lanvin, E. H., Solid phase microextraction application in gas chromatography/olfactometry dilution analysis, *J. Agric. Food Chem.*, 47, 1616, 1999.
15. Wardencki, W., Michulec, M., and Curylo, J., A review of theoretical and practical aspects of solid-phase microextraction in food analysis, *Int. J. Food Sci. Technol.*, 39, 703, 2004.
16. O'Riordan, P. J. and Delahunty, C. M., Comparison of volatile compounds released during the consumption of Cheddar cheese with compounds extracted by vacuum distillation using gas chromatography-olfactometry, *Flavour Fragr. J.*, 16, 425, 2001.
17. James, A. T. and Martin, A. J. P., Gas-liquid partition chromatography: the separation and micro-estimation of volatile fatty acids from formic acid to dodecanoic acid, *Biochem. J.*, 50, 679, 1952.
18. Ettre, L. S. and Hinshaw, J. V., *Basic Relationships of Gas Chromatography*, 1st edn., Advanstar Data, Cleveland, OH, 1993, Chapter 4.
19. Imhof, R. and Bosset, J. O., The performance of various capillary columns for the analysis of volatile flavor compounds in dairy products by dynamic headspace gas chromatography, *J. High Resol. Chromatogr.*, 17, 25, 1994.
20. Qian, M. C. and Burbank, H., Development of volatile sulfur compounds in heat-shocked and pasteurized milk cheese, *Int. Dairy J.*, 18, 811, 2008.
21. Aston, J. W. and Douglas, K., Detection of carbonyl sulphide in Cheddar cheese headspace, *J. Dairy Res.*, 48, 473, 1981.
22. Parliament, T. H., Kolor, M. G., and Rizzo, D. J., Volatile components of Limburger cheese, *J. Agric. Food Chem.*, 30, 1006, 1982.
23. Lundén, A. et al., High trimethylamine concentration in milk from cows on standard diets is expressed as fishy off-flavour, *J. Dairy Res.*, 69, 383, 2002.
24. Kováts, E., Gas-chromatographische Charakterisierung organischer Verbindungen. Teil 1: Retentionsindices aliphatischer Halogenide, Alkohole, Aldehyde und Ketone, *Helv. Chim. Acta*, 51, 1915, 1958.
25. van den Dool, H. and Kratz, P. D., A generalization of the retention index system including linear temperature programmed gas-liquid chromatography, *J. Chromatogr.*, 11, 463, 1963.
26. Vékey, K., Mass spectrometry and mass-selective detection in chromatography, *J. Chromatogr. A*, 921, 227, 2001.
27. Dirinck, P. and De Winne, A., Flavour characterisation and classification of cheeses by gas chromatographic–mass spectrometric profiling, *J. Chromatogr. A*, 847, 203, 1999.
28. Barbieri, G. et al., Study of the volatile fraction of Parmesan cheese, *J. Agric. Food Chem.*, 42, 1170, 1994.
29. Shiratsuchi, H. et al., Volatile flavor compounds in spray-dried skim milk powder, *J. Agric. Food Chem.*, 42, 984, 1994.
30. Fernández-García, E., Use of headspace sampling in the quantitative analysis of artisanal Spanish cheese aroma, *J. Agric. Food Chem.*, 44, 1833, 1996.
31. Adahchour, M. et al., Trace-level determination of polar flavour compounds in butter by solid-phase extraction and gas chromatography–mass spectrometry, *J. Chromatogr. A*, 844, 295, 1999.
32. Liu, Z. and Phillips, J. B., Comprehensive 2-dimensional gas chromatography using an on-column thermal modulator interface, *J. Chromatogr. Sci.*, 1067, 227, 1991.
33. Phillips, J. B. and Beens, J., Comprehensive two-dimensional gas chromatography: A hyphenated method with strong coupling between the two dimensions, *J. Chromatogr. A*, 856, 331, 1999.
34. Schoenmakers, P., Marriott, P., and Beens, J., Nomenclature and conventions in comprehensive multidimensional chromatography, *LC-GC Eur.*, June, 1, 2003.

© 2011 by Taylor and Francis Group, LLC

35. Adahchour, M. et al., Recent developments in comprehensive two-dimensional gas chromatography (GC × GC) IV. Further applications, conclusions and perspectives, *TrAC*, 25, 821, 2006.
36. Adahchour, M. et al., Improved determination of flavour compounds in butter by solid-phase (micro) extraction and comprehensive two-dimensional gas chromatography, *J. Chromatogr. A*, 1086, 99, 2005.
37. Adahchour, M. et al., Comprehensive two-dimensional gas chromatography with time-of-flight mass spectrometric detection for the trace analysis of flavour compounds in food, *J. Chromatogr. A*, 1019, 157, 2003.
38. Fuller, G. H., Steltenkamp, R. S., and Tisserand, G. A., The gas chromatograph with human sensor: perfumer model, *Ann. N. Y. Acad. Sci*., 116, 711, 1964.
39. Richardson, A., Measurement of fragrance perception, in *The Chemistry of Fragrances, 1st edn*., Pybus, D. H. and Sell, C. S., Eds., Royal Society of Chemistry, Cambridge, 1999, Chapter 8.
40. Meilgaard, M., Civille, G. V., and Carr, B. T., *Sensory Evaluation Techniques*, CRC Press, Boca Raton, 1991.
41. Acree, T. E., Barnard, J., and Cunningham, D., A procedure for the sensory analysis of gas chromatographic effluents, *Food Chem*., 14, 273, 1984.
42. Ullrich, F. and Grosch, W., Identification of the most intense volatile flavour compounds formed during autoxidation of linoleic acid, *Z. Lebensm. Unters. Forsch*., 184, 277, 1987.
43. Moio, L. et al., Odorous constituents of ovine milk in relationship to diet, *J. Dairy Sci*., 79, 1322, 1996.
44. Christensen, K. R. and Reineccius, G. A., Aroma extract dilution analysis of aged Cheddar cheese, *J. Food Sci*., 60, 218, 1995.
45. Suriyaphan, O. et al., Characteristic aroma components of British Farmhouse Cheddar cheese, *J. Agric. Food Chem*., 49, 1382, 2001.
46. McDaniel, M. R. et al., Pinot noir aroma: A sensory/gas chromatographic approach, in *Flavors and Off-Flavors* (*Developments in Food Science Vol. 24*), Charalambous, G., Ed., Elsevier Science Publishers, Amsterdam, 1992, pp. 23–26.
47. Linssen, J. P. H. et al., Combined gas chromatography and sniffing port analysis of volatile compounds of mineral water packed in polyethylene laminated packages, *Food Chem*., 46, 367, 1993.
48. Pollien P. et al., Hyphenated headspace-gas chromatography-sniffing technique: Screening of impact odorants and quantitative aromagram comparisons, *J. Agric. Food Chem*., 45, 2630, 1997.
49. Ott, A., Fay, L. B., and Chaintreau, A., Determination and origin of the aroma impact compounds of yogurt flavor, *J. Agric. Food Chem*., 45, 850, 1997.
50. Casimir, D. J. and Whitfield, F. B., Flavour impact values, a new concept for assigning numerical values for the potency of individual flavour components and their contribution to the overall flavour profile, *Ber. Int. Fruchtsaftunion*., 15, 325, 1978.
51. Avsar, Y. K. et al., Characterization of nutty flavor in Cheddar cheese, *J. Dairy Sci*., 87, 1999, 2004.
52. Vangtal, A. and Hammond, E. G., Correlation of the flavor characteristics of Swiss-type cheeses with chemical parameters, *J. Dairy Sci*., 69, 2982, 1986.
53. Grosch, W. et al., Aroma extract dilution analysis versus aroma extract concentration analysis, in *Gas Chromatography-Olfactometry: The State of the Art, 1st edn*., Leland, J. V., Schieberle, P., Buettner, A., and Acree, T. E., Eds., American Chemical Society, Washington, D.C., 2001, Chapter 12.
54. Kubíčková, J. and Grosch, W., Evaluation of potent odorants of Camembert cheese by dilution and concentration techniques, *Int. Dairy J*., 7, 65, 1997.
55. Dumont, J. P., Rogger, S., and Adda, J., Neutral volatiles in Camembert cheese, *Le Lait*, 54, 501, 1974.
56. Zehentbauer, G. and Reineccius, G. A., Determination of key aroma components of Cheddar cheese using dynamic headspace dilution assay, *Flavour Fragr. J*., 17, 300, 2002.
57. Milo, C. and Reineccius, A., Identification and quantification of potent odorants in regular-fat and low-fat mild Cheddar cheese, *J. Agric. Food Chem*., 45, 3590, 1997.
58. Singh, T. K., Drake, M. A., and Cadwallader, K. R., Flavor of Cheddar cheese: A chemical and sensory perspective, *Compr. Rev. Food Sci. Food Saf*., 2, 165, 2003.

© 2011 by Taylor and Francis Group, LLC

59. Qian, M. and Reineccius, G., Potent aroma compounds in Parmigiano Reggiano cheese studied using a dynamic headspace (purge-trap) method, *Flavour Fragr. J.*, 18, 252, 2003.
60. Curioni, P. M. G. and Bosset, J. O., Key odorants in various cheese types as determined by gas chromatography-olfactometry, *Int. Dairy J.*, 12, 959, 2002.
61. Marsili, R. T., SPME-MS-MVA as an electronic nose for the study of off-flavors in milk, *J. Agric. Food Chem.*, 47, 648, 1999.
62. Marsili, R. T., Shelf-life prediction of processed milk by solid-phase microextraction, mass spectrometry, and multivariate analysis, *J. Agric. Food Chem.*, 48, 3470, 2000.
63. Pérès, C., Viallon, C., and Berdagué, J. -L., Solid-phase microextraction-mass spectrometry: A new approach to the rapid characterization of cheeses, *Anal. Chem.*, 73, 1030, 2001.
64. Lindinger, W., Hansel, A., and Jordan, A., On-line monitoring of volatile organic compounds at ppt level by means of proton-transfer-reaction mass spectrometry (PTR-MS): Medical application, food control and environmental research, *Int. J. Mass Spectrom. Ion Proc.*, 173, 191, 1998.
65. Boscaini, E. et al., Gas chromatography-olfactometry (GC-O) and proton transfer reaction-mass spectrometry (PTR-MS) analysis of the flavour profile of Grana Padano, Parmigiano Reggiano, and Grana Trentino cheeses, *J. Agric. Food Chem.*, 51, 1782, 2003.
66. Gardner, J. W. and Bartlett, P. N., *Electronic noses principles and applications, 1st edn.*, Oxford University Press, New York, 1999, Chapter 5.
67. Winquist, F. et al., An electronic tongue in the dairy industry, *Sens. Actuators B*, 111–112, 299, 2005.
68. Magan, N., Pavlou, A., and Chrysanthakis, I., Milk-sense: A volatile sensing system recognises spoilage bacteria and yeasts in milk, *Sens. Actuators B*, 72, 28, 2001.
69. Haugen, J. E., Electronic noses in food analysis, in *Headspace Analysis of Foods and Flavours: Theory and Practice, 1st edn.*, Rouseff, R. L. and Cadwallader, K. R., Eds., Plenum Press, New York, 2001, Chapter 4.
70. Trihaas, J., Vognsen, L., and Nielsen, P. V., Electronic nose: New tool in modelling the ripening of Danish blue cheese, *Int. Dairy J.*, 15, 679, 2005.
71. Trihaas, J., and Nielsen, P. V., Electronic nose technology in quality assessment: Monitoring the ripening process of Danish Blue cheese, *J. Food Sci.*, 70, E44, 2005.
72. Visser, F. R. and Taylor, M., Improved performance of the Aromascan A32S electronic nose and its potential for detecting aroma differences in dairy products, *J. Sensory Stud.*, 13, 95, 1998.
73. Ampuero, S. and Bosset, J. O., The electronic nose applied to dairy products: A review, *Sens. Actuators B*, 94, 1, 2003.
74. Winquist, F. et al., Monitoring of freshness of milk by an electronic tongue on the basis of voltammetry, *Meas. Sci. Technol.*, 9, 1937, 1998.
75. Audoin, V. et al., Limitations in the use of odor activity values to determine important odorants in food, in *Gas Chromatography–Olfactometry: The State of the Art, 1st edn.*, Leland, J. V., Schieberle, A., Buettner, A., and Acree, T. E., Eds., American Chemical Society, Washington, D.C., 2001, Chapter 14.
76. Patton, S. and Josephson, D., A method for determining significance of volatile compounds in foods, *Food Res.*, 22, 316, 1957.
77. Rothe, M. and Thomas, B., Aromastoffe des Brotes, *Lebensm. Unters. Forsch.*, 119, 302, 1963.
78. Schieberle, P. et al., Character impact odour compounds of different kinds of butter, *Lebensm. Wiss. Technol.*, 26,347, 1993.
79. Czerny, M., Mayer, F., and Grosch, W., Sensory study on the character impact odorants of roasted arabica coffee, *J. Agric. Food Chem.*, 47, 695, 1999.
80. Dimos, A., Urbach, G. E., and Miller, A. J., Changes in flavour and volatiles of full-fat and reduced fat Cheddar cheeses during maturation, *Int. Dairy J.*, 6, 981, 1996.
81. Ishii, R. et al., Relating consumer and trained panels' discriminative sensitivities using vanilla flavored ice cream as a medium, *Food Qual. Pref.*, 18, 89, 2007.

© 2011 by Taylor and Francis Group, LLC

82. Kubíčková, J. and Grosch, W., Evaluation of flavour compounds of Camembert cheese, *Int. Dairy J.*, 8, 11, 1998.
83. Andersson, R. E. et al., Effect of a heat-resistant microbial lipase on flavor of ultra-high-temperature sterilized milk, *J. Dairy Sci.*, 64, 375, 1981.
84. Collins, E. B. and Moustafa, H. H., Sensory and shelf-life evaluations of Cottage cheese treated with potassium sorbate, *J. Dairy Sci.*, 52, 439, 1969.
85. Biede, S. L., Reinbold, G. W., and Hammond, E. G., Influence of *Lactobacillus bulgaricus* on commercial Swiss cheese, *J. Dairy Sci.*, 60, 123, 1977.
86. Delarue, J. and Sieffermann, J. -M., Comparison with a conventional descriptive method for the evaluation of the flavour of fruit dairy products, *Food Qual. Pref.*, 15, 383, 2004.
87. Dairou, V. and Sieffermann J. -M., A comparison of 14 jams characterized by conventional profile and a quick original method, the Flash profile, *J. Food Sci.*, 67, 826, 2002.
88. Carpino, S. et al., Chemometric analysis of Ragusano cheese flavor, *J. Agric. Food Chem.*, 50, 1143, 2002.
89. Biasoli, F. et al., Correlation of PTR-MS spectral fingerprints with sensory characterisation of flavour and odour profile of "Trentingrana" cheese, *Food Quality Pref.*, 17, 63, 2006.
90. Carunchia Whestine, M. E. et al., Identification and quantification of character aroma components in fresh Chevre-style goat cheese, *J. Food Sci.*, 68, 2441, 2003.
91. Baigrie, B., Introduction, in *Taints and Off-Flavours in Food, 1st edn.*, Baigrie, B., Ed., Woodhead Publishing Ltd., Cambridge, 2003, Chapter 1.
92. Rychlik, M. and Bosset, J. O., Flavour and off-flavour compounds of Swiss Gruyère cheese. Evaluation of potent odorants, *Int. Dairy J.*, 11, 895, 2001.
93. Rychlik, M. and Bosset, J. O., Flavour and off-flavour compounds of Swiss Gruyère cheese. Identification of key odorants by quantitative instrumental and sensory studies, *Int. Dairy J.*, 11, 903, 2001.
94. Carunchia Whetstine, M. E., Drake, M. A., and Cadwallader, K. R., Characterization of aroma compounds responsible for the rosy/floral flavor in Cheddar cheese, *J. Agric. Food Chem.*, 45, 850, 1997.
95. Badings, H. T., Cold-storage defects in butter and their relation to the autoxidation of unsaturated fatty acids, *Ned. Melk Zuiveltijdschr.*, 24, 147, 1970.
96. Swoboda, P. A. T. and Peers, K. E., Metallic odor caused by vinyl ketones formed in the oxidation of butterfat. The identification of octa-1-cis-5-dien-3-one, *J. Sci. Food Agric.*, 28, 1019, 1977.
97. Huß, M. and Kessler, H. G., Einfluß des Butterungsrahmfettgehaltes auf die sensorischen Eigenschaften von Buttermilch, *Deutsche Molkerei-zeitung*, 49, 1570, 1989.
98. Heiler, C. and Schieberle, P., Studies on the metallic off-flavour in buttermilk: Identification of potent aroma compounds, *Lebensm.-Wiss. U.-Technol.*, 29, 460, 1996.
99. Mounchilli, A. et al., HS-SPME gas chromatographic characterization of volatile compounds in milk tainted with off-flavour, *Int. Dairy J.*, 15, 1203, 2005.
100. Wellnitz-Ruen, W., Reineccius, G. A., and Thomas, E. L., Analysis of the fruity off-flavor in milk using headspace concentration capillary column gas chromatography, *J. Agric. Food Chem.*, 30, 512, 1982.
101. Nursten, H. E., The flavour of milk and dairy products: I. Milk of different kinds, milk powder, butter and cream, *Int. J. Dairy Technol.*, 50, 48, 1997.

© 2011 by Taylor and Francis Group, LLC

Chapter 23

Determination of Identity and Quality of Dairy Products

Romdhane Karoui

Contents

23.1 Introduction....414
23.2 Traditional Techniques Used for Monitoring Cheese Ripening and Determination of the Quality and Authenticity of Dairy Products 414
23.2.1 Physicochemical Analyses 414
23.2.2 Liquid Chromatographic Techniques.... 416
23.2.3 Gas Chromatographic Techniques 416
23.2.4 Rheological Techniques 417
23.2.5 Sensory Analysis 418
23.3 Spectroscopic Techniques Used for the Determination of the Quality and Authenticity of Dairy Products.... 419
23.3.1 Control of Coagulation, Syneresis, and Heat Treatment 419
23.3.2 Monitoring of Cheese Ripening 421
23.3.3 Measurements of Cheese Composition, Cheese Rheology, and Sensory Attributes 423
23.3.4 Cheese Authenticity Determination 425
23.4 Conclusion.... 429
References 429

© 2011 by Taylor and Francis Group, LLC

23.1 Introduction

There is an increasing demand of the consumers and actors of the food industry sector to have means of measurement allowing the characterization of food. Dairy products such as milk, ice cream, yogurt, butter, cheese, and the like are in considerable demand, command premium prices and are, therefore, vulnerable to economic adulteration. The determination of the quality and identity of these products is an important issue for food processors, retailers, regulatory authorities, and consumers. It is also valuable for ensuring fair competition and as a means of protecting consumers against fraud due to mislabeling. Different analytical techniques could be utilized: (1) the traditional analytical strategies that have relied on wet chemistry to determine the amount of a marker compound or compounds in a suspect material and a subsequent comparison of the value(s) obtained with those established for equivalent material of known provenance [1]. This approach suffers from a number of disadvantages, namely, the ever-increasing range of analytes, which must be included in any test procedures and the limited knowledge of the range of each constituent in normal lots of the substance. In addition, the above-mentioned methods required sophisticated analytical equipments and skilled operators; they are also time consuming and need both the purchase and disposal of chemical reagents. For all these reasons, there is a continuing demand for (2) new, rapid, and relatively cheaper methods for direct quality measurement in food and food ingredients. Spectroscopic techniques, such as near infrared (NIR), midinfrared (MIR), front-face fluorescence spectroscopy (FFFS), stable isotope, and nuclear magnetic resonance (NMR) have demonstrated their ability for the determination of the quality and/or geographical origins of dairy products [2]. This chapter will provide the reader with a review of the use of different techniques for the assessment of the quality of dairy products. This chapter also examines some of the reported approaches adopted for the determination of the identity and quality of dairy products by using multivariate statistical analyses.

23.2 Traditional Techniques Used for Monitoring Cheese Ripening and Determination of the Quality and Authenticity of Dairy Products

23.2.1 Physicochemical Analyses

Cheese-making is dependent upon local, regional, or national traditions leading to differences between cheeses of the same variety but of different origins. Starters, heating temperature of the curd, brining, and ripening time are some of the processing parameters that are typical for a defined region and lead to chemical, physical, or microbial secondary indicators. Indicators of origin for produced dairy products were reported to be subdivided into primary and secondary indicators [2]. The first indicators are not influenced by the technology applied for manufacture or ripening conditions but depend only on the feed of the cows, while the secondary indicators depend on the technology used for manufacturing the product. Guinot-Thomas et al. [3] monitored the changes that occur in milk kept at 4°C for 24 and 48 h. The authors showed that no significant difference for nitrogenous compounds (caseins, whey proteins, and nonprotein nitrogen) was observed between the investigated milk samples. However, mineral composition presented significant changes; indeed, milk samples kept at 4°C for 24 h exhibited a decrease of 50%, 36%, 30%, and 40% for calcium, phosphorus, magnesium, and sodium, respectively, while milk kept at 4°C during 48 h showed a decrease of 75%, 22%, 53%, and 50% for calcium, phosphorus, magnesium, and sodium, respectively.

© 2011 by Taylor and Francis Group, LLC

Bugaud et al. [4] pointed out the impact of pastures given to the herd on the physicochemical parameters of both milk and cheese samples. In their research, the protein amount of milk samples produced in mountain pastures ($n = 5$, 1500–1850 m) was similar to those produced in valley pastures ($n = 5$, 850–1100 m), while fat content of milk and cheese samples from the mountain were found to be lower than that of the valley. The obtained results confirmed partially previous findings performed on Abondance semi-hard French cheese made with milk produced in the mountain which presented the highest values of most indicators of proteolysis, while those produced with milk produced in the valley showed the lowest ones [5].

Recently, Pillonel et al. [6] pointed out that some chemical parameters such as total nitrogen (TN), water-soluble nitrogen (WSN), 12% TCA soluble nitrogen (TCA-SN), and pH could be considered as promising parameters among others to discriminate Emmental cheeses produced during winter (110 samples) and summer (73 samples) periods and originating from different European countries, in agreement with previous findings of Millán et al. [7] who used some chemical parameters (such as ammonia nitrogen, nonprotein nitrogen, moisture, salt, and pH) for differentiating between 80 cheeses representative of 10 varieties of Spanish cheeses. By using discriminant analysis (DA), 10% of correct classification was obtained. One of the main conclusions of this study was that the physicochemical parameters could be considered as a suitable tool for discriminating cheeses according to their varieties.

Recently, Maâmouri et al. [8] used some physicochemical parameters (pH, density, nonfat in dry matter [DM], fat, protein, lactose, ash, and freezing point) for discriminating Sicilo-Sarde ewe's milk during the lactation period after replacing soybean meal with scotch bean in the feed ration. Some physicochemical parameter (density, protein, and nonfat DM levels) were found to be significantly ($P \leq 0.05$) lower at the beginning of the lactation period, whereas the freezing point values showed an opposite trend. In order to have into account the whole data sets, principal component analysis (PCA) was applied to the normalized data sets. The obtained result is shown in Figure 23.1. According to the principal component 2 (PC2) accounting for 24.4% of the total variance, milk from ewes fed on scotch bean meal presented mostly negative scores, while milk produced from ewes fed on soybean meal exhibited mostly positive score values. The authors concluded that the composition of diets had an effect on the physicochemical parameters of milk.

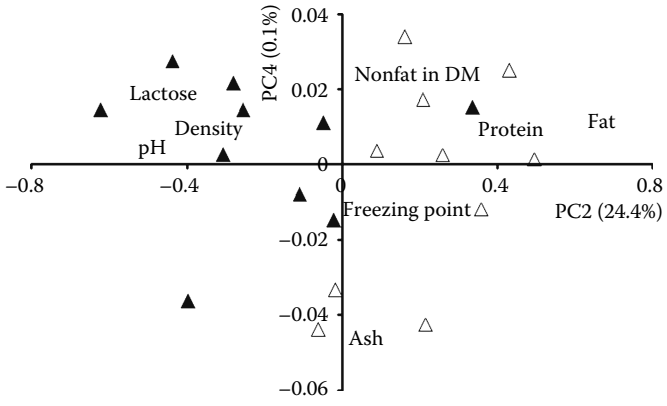


Figure 23.1 PCA similarity map determined by principal components 2 (PC2) and 4 (PC4) of the physicochemical parameters recorded on Sicilo-Sarde ewe's milk fed soybean meal (Δ) and scotch bean (▲) during lactation period.

© 2011 by Taylor and Francis Group, LLC

The same research group continued this work by recording physicochemical parameters on two genotypes ewe's (Sicilo-Sarde and Comisana) milk during lactation period. The PCA performed on the physicochemical period did not allow a good discrimination between milk samples produced from the two-genotype ewe's [9]. The authors concluded that the physicochemical analyses could not be considered as a powerful tool to identify milk samples according to their breeds, but recommended further investigations in this area of study.

23.2.2 Liquid Chromatographic Techniques

Liquid chromatograph could be used for dairy compounds that cannot be volatilized readily. O'shea et al. [10] used reverse phase high-performance liquid chromatography (RP-HPLC) to analyze water-soluble fraction of 60 Cheddar cheeses, varying in age (mild, mature, and extra-mature) and flavor quality (defective, nondefective). Only 33.3% and 48.3% of samples were correctly classified. Using the total concentration of free amino acids, 70% of correct classification was obtained for all the cheeses, while only 20% of mature cheeses were correctly classified. In a similar approach, Pripp et al. [11,12] applied PCA and hierarchical cluster analysis (HCA) to the RP-HPLC chromatograms of ethanol (70%) soluble and insoluble fractions and free amino acids to evaluate proteolysis in Cheddar-type model cheeses made by the use of different single-strain starters. From the PCA applied to the RP-HPLC chromatograms of ethanol (70%) soluble and insoluble fractions on cheeses that were 2 months old, the researchers concluded that group strains could be classified according to their effects on chromatographic profiles and free amino acids. Ferreira and Caçote [13] continued this work and utilized RP-HPLC to asses its potential for detecting and quantifying bovine, ovine, and caprine milk percentages in milks and cheeses. As expected, different chromatographic profiles were obtained for each type of milk binary mixtures. In addition, similar chromatographic profiles were obtained for each milk mixture and the respective fresh and ripened cheeses. One of the main conclusions of this study was that RP-HPLC could be considered as a very sensitive and accurate method for studying milk percentage as well as fresh and ripened cheeses made from binary mixtures of bovine, ovine, or caprine raw milks.

In a similar approach, Bara-Herczegh et al. [14] applied multivariate statistical analysis to identify the indices of secondary proteolysis by using HPLC of 40 Hungarian Trappist cheeses throughout ripening as well as during storage for 28, 42, 56, and 70 days. The authors concluded that the results obtained could be possible to monitor the significant changes of fractions of different molecular weight during the ripening time and shelf-life using HPLC.

Frau et al. [15] used an amino analyzer by ion-exchange chromatography on a sulfonated polystyrene column with postcolumn ninhydrin derivation to quantify free amino acids in Mahon cheese made with raw milk (three batches) and pasteurized milk (two batches). The cheeses were analyzed at 10, 60, 150, and 300 days of ripening. The authors applied PCA to the 27 amino acids and derived compounds and the results obtained allowed the discrimination of cheeses according to their ripening times and the quality of milk used for producing the cheeses.

23.2.3 Gas Chromatographic Techniques

Flavor compounds in dairy products are characteristics; consequently, the quantity and quality of flavor constituents analyzed by gas chromatography could be used as an efficient tool for determining the quality and identity of dairy products [16].

© 2011 by Taylor and Francis Group, LLC

Terpene content in dairy products are influenced by the feed given to the herd and especially by grazed herbage. In this context, Viallon et al. [17] utilized dynamic head space to extract monoterpenes and sesquiterpenes in milk fat, and then gas chromatography to separate these compounds collected from different cows fed successively with forage containing high and low amounts of terpenes. The modification of the plant species composition of forages was found to strongly influence the proportions and quantities of monoterpenes and sesquiterpenes in milk fat.

In a similar approach, Fernandez et al. [18] used dynamic head space-gas chromatography–mass spectrometry (DHS-GC–MS) to discriminate 35 milk samples produced in both high- and low-land region in France. The milk samples were collected during both the grazing period (spring and summer) and the stabling period (winter). Correct classification of 100% was observed for milk samples according to their geographical origin irrespective of season herd management pattern. The authors concluded that terpene compounds could provide useful fingerprints for the characterization of dairy products according to their geographical origin and their production conditions.

In another approach, Collomb et al. [19] used gas chromatography for quantifying fatty acid composition of 44 summer milk samples collected from different geographical sites located at different altitudes (lowlands, mountains, and highlands). Milk from highland regions exhibited smaller level of saturated short- and medium-chain fatty acids, and more polyunsaturated fatty acids, than milk produced in the lowlands, in agreement with the findings of Bosset et al. [20] regarding research on cheeses, Cornu et al. [21] utilized DHS-GC–MS for discriminating two French cheeses: Saint-Nectaire and Cantal. The investigated cheeses were produced from raw and pasteurized milk. The authors reported that milk pasteurization did not induce significant changes in the terpenes profile of cheese, while significant difference was found between Cantal and Saint-Nectaire cheeses. One of the main conclusions of this study was that cheese-making procedure was the most important factor inducing changes in terpene profiles, possibly due to the physicochemical conditions applied, microbial population, and the duration of cheese maturation period, in agreement with the findings of Pillonel et al. [22] who succeeded to discriminate Emmental cheeses produced in Switzerland (90% of correct classification) from those made in France, Finland, Germany, and Australia).

23.2.4 Rheological Techniques

Commonly, fluid milk and cream are considered examples of liquids, and hard cheeses as an example of solid. But concentrated milk, yogurt, butter, ice cream, and several types of cheese could show an intermediate behavior as viscoelastic [23]. Texture properties of dairy products play a key role in consumer acceptance of cheese [4,5,24,25]. Thus rheological characterization of dairy products is important as a means of determining body and texture for quality and identity as a function of composition, processing techniques, and storage conditions.

The effect of temperature on the viscosity of milk was reported by Gryzowska and Tuszynsky [26]. The authors pointed out that temperatures less than 50°C presented no effect on the viscosity of skim milk, while temperatures above 60°C induced an increase in the viscosity, even when temperature was applied for a short time. The results obtained were confirmed after partially by Jeurnink and DeKruif [27] who found that the viscosity of skim milk increased after heat treatments at temperature above 70°C. Quality attributes such as texture, consistency, firmness, curd tension, and flow properties of yogurt were measured with good satisfaction and allowed improvement of yogurt quality for consumer satisfaction. Because the network structure of yogurt plays an

© 2011 by Taylor and Francis Group, LLC

important role in the viscoelasticity, dynamic testing rheology is finding an excellent field of application in analyzing the viscoelastic nature of yogurt affected by process variables and measuring conditions [28–30].

Vlahopoulou and Bell [31] utilized dynamic tests to identify the viscoelastic differences between ropy and nonropy yogurts. The storage and loss moduli of the ropy gels were found to be lower than those corresponding to nonropy yogurts. Recently, Köksoy and Kiliç [32] investigated the effect of different levels of water and salt on the rheological properties and serum separation during storage of traditionally manufactured yogurts. The yoghurt samples were prepared by the addition of water at levels of 30 or 50 g/100 g and salt at levels of 0, 0.5, or 1 g/100 g and stored at 4°C. The results obtained showed that the consistency coefficient decreased and the flow behavior index increased dramatically with increasing levels of water and salt.

Regarding the texture of butter, Dixon and Parekh [33] examined different analytical techniques: penetration, cutting, extrusion, compression, and spreadability. Of these five instrumental methods, compression and extrusion were found to be the most used methods because of their high reproducibility, precision, and simplicity.

Recently, Raphaelides et al. [34] used dynamic testing rheology to monitor changes occurring in Halloumi cheeses throughout ripening, manufactured either from cows' milk or ewes' milk. Before the starting of ripening stage, bovine Halloumi was more rigid than the ovine Halloumi. In addition, the elasticity modulus of ovine Halloumi remains practically unchanged after an aging period of 15 days, while those produced from bovine Halloumi requires an aging period of 30 days to reach a constant elastic modulus value. After 30 days, the two Halloumi types presented the same values of storage modulus. The same technique was used to monitor changes that occurred in semi-hard and hard cheeses as a function of temperature [35]. The storage modulus (G'), the loss modulus (G''), and the complex viscosity (η^*) decreased while strain and tan (δ) increased as the temperature increased from 5°C to 60°C. The same research group outlined that G' and G'' increased, whereas tan (δ) and the strain decreased from the surface to the inner part of the three soft different cheeses [36].

23.2.5 Sensory Analysis

Sensory analysis of food involves the measurement, interpretation, and understanding of human responses to the properties of food perceived by the senses such as sight, smell, taste, touch, and hearing [37,38]. Recently, the impact of different processing conditions on the sensory characteristics of milk was reported to have no significant effect [39]. Horimoto and Nakai [40] used sensory analysis to detect off-flavors of milk subjected to light-induced, cooked, and heated flavor milk. The authors have then applied PCA to the data sets and only slight differences were obtained. In another study, Quinones et al. [41,42] determined the effect of substitution of nonfat dry milk with a protein standardization by ultrafiltration and the results obtained reported that sensory texture and appearance descriptors were affected by both the protein standardization and the fat content. Regarding research on cheese, Lebecque et al. [43] studied the sensory attributes of 25 Salers PDO cheeses presenting 3.5 months ripening time. Eight attributes for texture profiling were studied, and significant differences were obtained between the cheeses. Indeed, the 25 investigated cheeses were classified into five groups. Recently, Ritvanen et al. [44] studied 44 reduced and full fat cheese types (Edam, Emmental, and Havarti) and significant differences in flavor and texture of full fat and reduced fat cheeses were observed by the panel.

© 2011 by Taylor and Francis Group, LLC

23.3 Spectroscopic Techniques Used for the Determination of the Quality and Authenticity of Dairy Products

Although the importance of the above-mentioned techniques is unquestionable, these methods are hardly possible to implement for practical use when many samples need to be analyzed online or at-line in the food industry. For practical reasons, the quality criteria of such products should be easily measurable. Simple and rapid methods are needed for quality control and for screening many samples in a research or development situation.

Spectroscopic techniques such as NIR, FT-MIR, FFFS, NMR, and stable isotope are becoming increasingly attractive analytical techniques for measuring quality parameters in dairy products with decreasing instrument prices and improved equipment and chemometric tools. The main advantages of using spectroscopic techniques are rapid sample data acquisition, the possibility of simultaneous determination of several quality parameters and the ability to replace expensive and time-consuming reference techniques.

23.3.1 Control of Coagulation, Syneresis, and Heat Treatment

The first step in cheese manufacture is the transformation of milk into a gel, following the addition of an enzyme that induces destabilization of the casein micelles. When sufficient micelles are destabilized, they aggregate together, forming a gel network (coagulum); the time taken to form this network is called the gel time. Over time, the firmness of the coagulum continues to develop until it is sufficiently firm to cut. This is known as the cutting time. Several studies have stressed the importance of obtaining objective online measurements for monitoring gel time, coagulum firmness, and cutting time during cheese manufacture to obtain high quality and consistent cheese products [45]. Originally, the cheese-maker established the cutting time based on his expertise. Although this method is accurate, it is not feasible in closed commercial vats. Indeed, during milk coagulation, the time at which the gel is cut directly affects the quality of the resulting curd, and hence, the finished cheese. If the gel is too firm when cut, the result will be higher losses of curd and fat. An increase in cheese moisture will also occur if the gel is cut before the optimum time. This has resulted in the development of a number of online sensors that can be used to successfully monitor milk coagulation. O'Callaghana et al. [46] pointed out the usefulness of NIR as an online method for monitoring the coagulation of milk without causing damage to the formation of curd. McMahon et al. [47] and Payne et al. [48] used diffuse reflectance technique during milk coagulation by utilizing photodiode light sources at 940 and 950 nm. In both cases, cutting time was predicted using parameters derived from the NIR reflectance profiles recorded during coagulation. However, these studies only monitored coagulation at a single wavelength. Laporte et al. [49] continued this work and used full spectrum information and partial least squares (PLS) regression. Reflectance spectra were acquired during coagulation in the 1100 and 2500 nm. The obtained results were considered promising by the authors since the percentage of coagulation determined by NIR presented a standard error of prediction (SEP) of 0.26%. Recently, Guillemin et al. [50] and Fagan et al. [51–53] examined the potential of NIR reflectance profiles for monitoring syneresis. Cutting of the coagulum initiates syneresis, which is the expulsion of whey from curd particles. Fagan et al. [51] proposed that a sensor-detecting NIR light backscatter in the 300–1100 nm in a cheese vat with a large field of view relative to curd particle size would have the potential to monitor both milk coagulation and curd syneresis. The

© 2011 by Taylor and Francis Group, LLC

authors pointed out that the response of the sensor was affected by temperature and that the sensor showed the potential tool for predicting whey fat content, curd moisture content, and curd yield. However, this preliminary study is only realized on a relatively small number of samples, and it would be interesting to validate the obtained results on a high number of samples. To respond to this request, Fagan et al. [52] continued this work and found that optical sensor could provide the information on gel assembly and curd shrinkage kinetics that were required for accurate predictions of whey fat losses and curd yield as well as for curd moisture control, in agreement with previous findings of Guillemin et al. [50] reporting that NIR could be considered as a potential technique for online determination of casein particle size distribution and of the volume fraction relative to the whey as a function of time.

In consideration with research that makes use of FFFS, Herbert et al. [54] used this technique to monitor milk coagulation at the molecular level. Three different coagulation processes were studied: the glucono-δ-lactone (GDL), rennet-induced coagulation system, and a mix system of GDL + rennet-induced coagulation. Emission fluorescence spectra of the protein tryptophanyl residues were recorded for each system during the milk coagulation kinetics. By applying the PCA to the normalized fluorescence spectral data corresponding to the three systems, detection of structural changes in casein micelles during coagulation and discrimination of different dynamics of the three coagulation systems was found. Herbert et al. [54] concluded that FFFS allowed the investigation of network structure and molecular interactions during milk coagulation.

Regarding the application of spectroscopic techniques for the evaluation of heat treatment, Dufour and Riaublanc [55] investigated the potential of FFFS to discriminate between raw, heated (70°C for 20 min), homogenized, and homogenized + heated milks. Different intrinsic probes were utilized (tryptophan and vitamin A). To extract information from the data sets, the authors applied, separately, PCA to the tryptophan and vitamin A fluorescence spectra, and a good discrimination between samples as a function of homogenization and heat treatment was found. One of the main conclusions of this study was that the treatments applied to milk-induced specific modifications in the shape of the fluorescence spectra, which were confirmed recently by Dufour and coworkers [56]. The authors used different intrinsic probes (aromatic amino acid and nucleic acid [AAA + NA], NADH, and FADH) for evaluating changes in milk samples following thermal treatments in the range of 57°C–72°C for 0.5 up to 30 min. The PCA applied on the normalized spectra allowed a good discrimination of milk samples subjected to different temperatures and times. Recently, the same research group used synchronous FFFS for the characterization at molecular level of milk changes during mild-heating from 4°C to 50°C and acidification in the 6.8–5.1 pH range. The spectra were acquired between 250 and 550 nm. By applying parallel factors (PARAFAC) analysis in the decomposition of the whole synchronous fluorescence data, contribution of each of the fluorescent compounds present in milk was pointed out for both heating and acidification [57]. However, the aforementioned researchers have only applied relatively low temperatures to milk samples, which did not allow monitoring the development of Maillard reaction browning, which was pointed out by Schamberger and Labuza [58]; the fluorescence spectra of milks which were processed for 5, 15, 20, 25, and 30 s in 5°C increments from 110°C to 140°C were found to be well correlated with hydroxylmethylfurfural (HMF). One of the main conclusion of this study was that FFFS could be considered as a very promising method for measuring Maillard browning in milk and could also be used as an online instrument for monitoring and control of thermal processing of milk, in agreement with the findings of Liu and Metzger [59] who have used FFFS for monitoring changes in nonfat dry milk ($n = 9$), collected from three different manufacturers and stored at four different temperatures (4°C, 22°C, 35°C, and 50°C) during 8 weeks of storage; a good discrimination of milk samples according to the storage time

© 2011 by Taylor and Francis Group, LLC

was depicted. In a similar approach, Feinberg et al. [60] also utilized fluorescence spectroscopy to identify five types of heat treatments (pasteurization, high pasteurization, direct UHT, indirect UHT, and sterilization) of 200 commercial milk samples stored at 25°C and 35°C for 90 days. By applying factorial discriminant analysis (FDA), Feinberg et al. [60] found that tryptophan fluorescence spectra could be considered as well adapted to discriminate sterilized milks and probably pasteurized milk from the other milk samples. However, tryptophan spectra failed to discriminate the other types of milk. An explanation could arise from the fact that fluorescence spectra were recorded in the pH 4.6 soluble fraction of milk sample inducing a loss of information, and not on native samples.

23.3.2 Monitoring of Cheese Ripening

During the ripening step, cheese undergoes a series of chemical, bacterial, and enzymatic reactions that are responsible for breakdown of the protein matrix and ultimately the development of the texture and sensory characteristics that are typical of ripened cheese. Thus, determination of the degree of ripening of cheese is important since it could help the cheese-maker to better understand the biochemical kinetics of ripening and in consequence to improve the ripening process [61,62]. Considerable interest exists in the development of instrumental techniques to enable more objective, faster, and less expensive assessments to be made in this area [63]. Burns and Ciurczak [64] used NIR to study the ripeness age of different varieties of Dutch cheeses (Edam and Gouda), with the goal to classify them into different aging groups (young, young-matured, matured, and extramatured). The results obtained from their study were considered as promising since a correlation coefficient of 0.92 and a standard error of calibration (SEC) values of 28 days for samples of ripeness interval between 25 and 412 days were obtained. Testing specific calibrations models of subgroups of reduced samples with ripeness intervals of 160 days induced better results since a correlation coefficient and SEC of 0.96 and 11, respectively. Recently, the NIR-Fourier transform infrared (FT-NIR) was applied to the Italian fresh cheese Crescenza [65], and a successful discrimination between cheeses according to their storage times was obtained. Indeed, three well-separated groups corresponding to the fresh (0–6 days), aged (8–10 days), and old (storage time > 10 days) were observed. The authors concluded that FT-NIR could be a suitable technique for the evaluation of the shelf-life in which Crescenza freshness is maintained. However, no interpretation at the molecular level was provided in this study.

Regarding the potential of FT-MIR for monitoring the ripening stage of cheese samples [66–68], outlined a good discrimination of 16 experimental semi-hard cheeses as a function of their ripening times (e.g., 1, 21, 51, and 81 days) by using the 1700–1500 cm^{-1} spectral region. Better results on the same research group were obtained following the use of FFFS [66,67]. By applying PCA to the normalized tryptophan fluorescence spectra, a good discrimination of cheeses presenting a ripening time of 21, 51, and 81 days was observed. The authors have then studied the spectral patterns, which were used to derive structural information at the molecular level. By studying the spectral pattern, a redshift of tryptophan spectra of aged cheeses was observed, suggesting that the environment of old cheeses was more hydrophilic than the young cheeses (1 day old). This phenomenon was explained by a partial proteolysis of casein as well as to the salting phenomenon, which could induce some changes in the tertiary and quaternary structures of casein micelles. Regarding fluorescence spectra of vitamin A, two shoulders located at 295 and 305 nm and a maximum located at 322 nm were observed [66]. In addition, the shape of the spectra changed with the ripening time. In order to determine the level of the link between FT-MIR

© 2011 by Taylor and Francis Group, LLC

and fluorescence spectra, canonical correlation analysis (CCA) was applied, on one hand, to the 1700–1500 cm^{-1} spectral region and tryptophan fluorescence spectra and, on the other hand, to the 3000–2800 cm^{-1} spectral region and vitamin A spectra [67]. A relatively high correlation was found since the first two canonical varieties with squared canonical correlation coefficient were higher than 0.58. The researchers concluded that FT-MIR and FFF spectra provided a common description of cheese samples throughout ripening. The obtained results were confirmed after on 24 semi-hard (Raclette) cheeses, produced during summer and autumn periods, analyzed at different ripening time (2, 30, and 60 days) using FFFS [68,69] and a good discrimination of cheeses according to their ripening time as well as a function of their production seasons was outlined by the authors. The researchers concluded that FFFS could be considered as a promising tool considering the significant effect of the season on the characterization of chesses.

In a similar approach, Martín-del-Campo et al. [61] used FT-MIR for monitoring the ripening stage of Camembert-type-cheese produced at a pilot scale. Cheese samples were analyzed at two different zones (core and under-rind) during the first 10 days of ripening as well as after 13, 15, 17, 20, and 27 days of ripening. From the results obtained, it was pointed out that the under-rind cheese samples presented some modifications in the spectra, while only a weak difference was observed between samples recorded on core spectra, throughout the ripening stage; these peaks were ascribed to some molecules, among them there are carbohydrate and organic acid associated bands located in the 1490–950 cm^{-1} spectral region [70]. Regarding the region located between 1700 and 1500 cm^{-1}, two characteristic bands of protein structures were observed: the *Amide I* located around at 1640 cm^{-1} ($\nu C = O$, $\nu C–N$) and the *Amide II* observed at 1550 cm^{-1} ($\delta N–H$ and $\nu C–N$), in agreement with previous findings [66].

The 3000–2800 cm^{-1} spectral region, characteristic of fat, was characterized by methylene bands located around 2920 and 2851 cm^{-1} and methyl peaks observed around 2954 and 2871 cm^{-1}. The authors outlined that the intensity of these peaks did not change significantly in the core, while significant changes were observed for spectra recorded on the under-rind zone, confirming the findings of [66,71] on semi-hard cheeses and soft cheeses, respectively.

In another study, Karoui et al. [72] recorded tryptophan, vitamin A, and riboflavin spectra on 12 semi-hard cheeses (Raclette), belonging to four brand products, which were produced during summer period at an industrial level. By applying common component and specific weights analysis (CCSWA) to the spectral data sets and physicochemical data, a good discrimination of the four brand cheeses was observed (Figure 23.2).

In another approach, De Angelis Curtis et al. [73] monitored the ripening of Italian PDO cheeses (6, 12, and 18 months) using both low and high NMR. Using low NMR, an increase in the amount of free water and a decrease in the level of bound water and total water for the cheese samples cut at 2, 5, 8 cm from the base of the wheel as well as for those cut at 2, 8, and 14 cm from the rind side of the wheel was pointed out. This phenomenon was ascribed to the hydrolysis of protein during ripening. Lipolysis could also contribute to this phenomenon, but this was of secondary importance with respect to proteolysis. Indeed, the same research group pointed out an increase in the level of serine, alanine, phenylalanine, and methionine and a decrease in the amounts of glutamate, leucine, and valine during the ripening stage, which was attributed by the authors to the proteolysis and to metabolic processes during the ripening time.

Kuo et al. [74] investigated changes in molecular mobility of water of Pasta Filata and non-Pasta Filata Mozzarella cheeses after 10 days of storage using NMR. The observed modifications were attributed to the changes in the physicochemical environments due to the structural rearrangements of protein matrix, contributing to the change of water mobility during aging. Moreover, some changes of both T_1 and T_2 were depicted during aging, and were attributed to the

© 2011 by Taylor and Francis Group, LLC

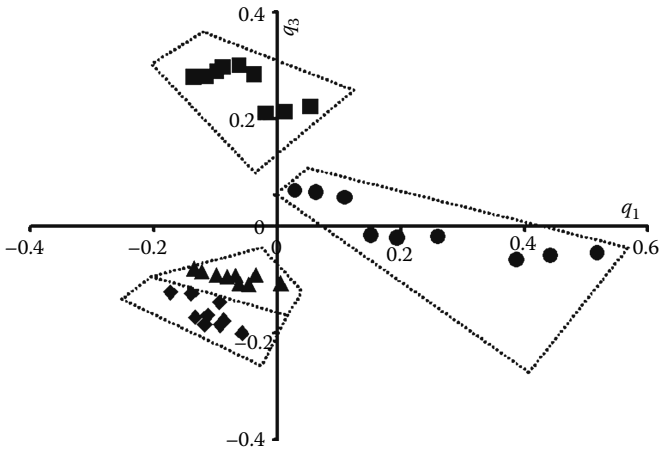


Figure 23.2 CCSWA similarity map defined by the common components 1 (q_1) and 3 (q_3) of A (♦), B (■), C (▲), and D (●) semi-hard cheeses at 60 days of ripening. CCSWA was performed on data tables obtained using riboflavin, tryptophan, and vitamin A fluorescence spectra and physicochemical data.

increase of hydration of proteins and to the change in the structure of protein matrix caused by proteolysis.

23.3.3 Measurements of Cheese Composition, Cheese Rheology, and Sensory Attributes

Cheeses are produced with a wide range of sensor, texture, and compositional parameters. The quality of any given type of cheese is mostly determined by its texture, which, in turn, is influenced by composition components and processing conditions. Manufacturers have traditionally depended on a wide range of physicochemical analyses to quantify major food components such as moisture, protein, and fat. Recently, Filho and Volery [75] used NIR to quantify total solid contents of fresh cheeses, having low, medium, and high solid contents, and a good discrimination of cheeses according to their solid contents was outlined. Indeed, all cheese samples located in the top cluster along the regression line belong to those, which had the highest solid contents, while those in the bottom cluster represent cheeses, which had the lowest solid contents. In a similar approach, Blaquez et al. [76] utilized NIR reflectance spectroscopy to predict moisture, fat, and inorganic salts in processed cheeses and accurate results were obtained. One of the main conclusions of this study was that NIR technique could be useful for off-line quality assessment of processed cheese.

Recently, the potential of NIR to predict maturity and sensory attributes of 24 Cheddar cheeses produced using five renneting enzymes and stored at 4°C for up to 9 months was assessed [63]. The NIR spectroscopy was found to have the ability to predict cheese maturity and several sensory attributes (crumbly, rubbery, chewy, etc.); with sufficient accuracy; the authors suggested the use of this technique for online purpose. In a similar approach, Blaquez et al. [77] used NIR reflectance spectroscopy in the range of 750–2498 nm to record spectra on cheeses which were stored for 2 and 4 weeks at 4°C. Nine sensory properties, five instrumental parameters, and cheese meltability were determined on cheese samples. The sensory attributes and instrumental

© 2011 by Taylor and Francis Group, LLC

texture measurements were found to be predicted with sufficient accuracy. The authors recommended the use of NIR reflectance spectroscopy for routine quality assessment of processed cheese, in agreement with the findings of McKenna [78] who have, however, used NIR transmission measurement on Edam, Gouda, Brie, Colby, and Cheddar and a range of SEP values varying from 0.12 to 0.35 were obtained using different methods of calibration for a number of types of cheese types.

Regarding the use of FT-MIR for the prediction of milk composition, Lynch and Barbano [79] outlined how well the calibration equations generated by using reconstituted "milk powders" could be used to predict the chemistry of raw milk samples. Regarding the prediction of fat content, the reconstituted powders were found not to provide an accurate fat calibration for testing raw milk samples. This phenomenon was ascribed by the authors to differences in the characteristics of the fat in the reconstituted powders and in raw milk. Considering protein content, comparable precisions for both types of calibration was depicted. Later, Sørensen et al. [80] assessed the potential FT-MIR for determining casein content in dairy cow's milk. The researchers applied PLS regression to the spectra and the obtained results showed SEP of 0.033% and 0.89% for casein concentrations in the range of 2.1%–4% and 70.7%–81%, respectively. The main conclusion of this study was that FT-MIR was found to be less sensitive to heat denaturation of whey proteins than the reference method. Recently, Etzion et al. [81] succeeded to predict protein concentrations by using FT-MIR of 26 milk standards for which the amount of proteins ranged from 2.27 to 3.90 g/100 g. The obtained findings were confirmed after by Iñón et al. [82] who assessed the potential of FT-MIR to predict nutritional parameters of 83 commercially milk bottles covering the whole range of available brand names and types of milk in Spain. By applying the PLS regression, relative precision of 0.062 g/100 g, 0.04 g/100 g, 0.039 g/100 g, 0.66 kcal 100/mL, and 2.1 mg of ca. 100/mL, were obtained, respectively for total fat, total protein, total carbohydrates, calories, and calcium, respectively. One of the main conclusions of this study was that FT-MIR could be used as a suitable technique for the classification of milk samples.

Recently, Martín-del-Campo et al. [62] utilized FT-MIR to predict some chemical parameters in soft cheeses (pH, acid-soluble nitrogen, nonprotein nitrogen, ammonia (NH_4^+), lactose, and lactic acid). By applying PLS regression, a good prediction of these parameters, except for that of pH was observed, in agreement with the findings of Karoui et al. [83] The authors concluded that, although the physicochemical parameters were determined at different ripening time, they were comparable to previous findings obtained on ripened cheeses. The authors [83] compared NIR and FT-MIR for predicting some chemical parameters of 91 Emmental cheeses produced during the winter time in Austria ($n = 4$), Finland ($n = 6$), Germany ($n = 13$), France ($n = 30$), and Switzerland ($n = 38$). The authors applied PLS regression with the leave-one-out cross-validation technique and the obtained results suggested the use of the NIR for the determination of fat and TN contents, and the FT-MIR for NaCl and NPN contents as well as for the pH. Similar results were obtained for WSN using the two techniques together. The authors have then combined spectra of both NIR and FT-MIR and concluded that no improvement of the results were obtained, since comparable results to those obtained from either the NIR or MIR were observed. The results obtained using FT-MIR were partially confirmed on Emmental cheeses produced during the summer period since the authors suggested the use of FT-MIR for NPN and WSN. Indeed, R^2 of 0.80 and 0.71 and ration of standard deviation to root mean square error of prediction (RPD) of 2.22 and 1.85, were obtained for WSN and NPN, respectively. However, the NaCl, pH, and TN were found to could be estimated, but with much lower precision [84].

The results obtained on Emmental cheeses were then partially confirmed on soft cheeses cut at two sampling zones (surface and center) [85]. Indeed, fat, DM, TN, and WSN contents were

© 2011 by Taylor and Francis Group, LLC

found to be the best predicted with the VIS-NIR models providing the lowest values of the root mean square error of prediction (RMSEP) of 1.32, 0.70, 0.11, and 0.10, respectively. Again, the combination of the VIS–NIR and MIR spectral slightly improved the prediction of the pH only. The authors suggested the use of VIS–NIR for the determination of fat, DM, TN, and WSN. The pH was found to be predicted from the two techniques with approximate quantitative prediction, while a difference between low and high levels of WSN/TN ratio could be determined by the VIS-NIR, MIR, or joint use of VIS–NIR–MIR. Regarding research on soft cheeses, Karoui and coworkers [86] also assessed the potential of FFFS for predicting some chemical parameters in cheeses. Tryptophan (excitation, 290 nm; emission, 305–450 nm), riboflavin (excitation, 380 nm; emission, 400–640 nm), and vitamin A fluorescence spectra (emission, 410 nm; excitation, 270–350 nm) were recorded on the investigated cheeses [86]. The results showed that fat, DM, fat in DM, and WSN were the best predicted with the vitamin A fluorescence spectra models providing the highest values of the correlation coefficient (R^2) was 0.88, 0.86, 0.86, and 0.84, respectively. The prediction of the pH was also successful using riboflavin fluorescence spectra (R^2 = 0.85). The WSN/TN ratio can also be predicted from the three intrinsic probes, but with much lower precision. The obtained results confirmed previous findings reporting that FFFS could be used for the prediction of the rheological parameter and melting points of cheeses [87,88]. Indeed, excellent predictions were obtained from the tryptophan and vitamin A models for fat (R^2 = 0.99 and 0.97, respectively), DM (R^2 = 0.94 and 0.96, respectively), fat in DM (R^2 = 0.92 and 0.99, respectively), TN (R^2 = 0.91 and 0.91, respectively). Excellent predictions were also obtained for WSN (R^2 = 0.96) and melting point (R^2 = 0.97) from vitamin A spectra. The results for pH were good (R^2 = 0.82) and approximate (R^2 = 0.76) with tryptophan and vitamin A, respectively. The authors concluded that FFFS might be used for rapid online determination of the melting point and physicochemical parameters of cheeses.

23.3.4 Cheese Authenticity Determination

Cheese authenticity is an emerging research area that is becoming increasingly important to the dairy sector. The requirement for manufacturers and producers to be able to demonstrate food chain traceability, together with a rise in consumer awareness in food products, has focused renewed interest in food authenticity determination [89].

The potential of NIR diffuse reflection in combination with multivariate chemometric tools for discriminating Emmental cheeses of various geographic origins was investigated by Pillonel et al. [90] The authors applied linear discriminant analysis (LDA) to the PCA scores, and 100% correct classification was found. Although, the obtained results were interesting, they are realized on a small number of samples (n = 20); thus the models were not very robust against the inclusion or exclusion of samples. Therefore, the obtained results should be regarded with precaution until validation on a large number of cheeses.

In this context, Karoui et al. [91,94] assessed the ability of NIR, FT-MIR, and FFFS for determining the geographic origin of European Emmental cheeses and Cheeses produced in Jura (France, Figure 23.3) [92–94]. Regarding cheeses produced during the winter period and investigated by NIR, a good classification of cheeses was achieved for 89% and 86.8% for the calibration and validation spectral data sets, respectively [94]. The FT-MIR results were comparable to those observed with NIR. Indeed, the 3000–2800 cm^{-1} spectral region allowed 84.1% and 85.7% of correct classification for the calibration and validation data sets, respectively. The classification obtained with the tryptophan fluorescence spectra was considerably lower, since only 67.6% and

© 2011 by Taylor and Francis Group, LLC

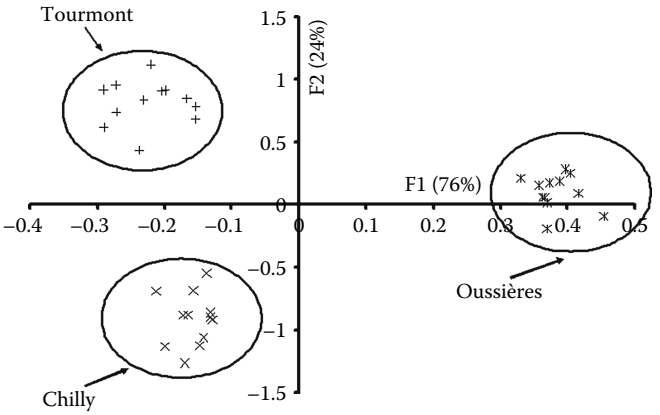


Figure 23.3 DA similarity map determined by discriminant factors 1 and 2 for mid-infrared spectra (1700–1500 cm^{-1}) of hard cheeses produced in three different regions in Jura (France).

41.7% for classification and validation spectra was obtained. But tryptophan fluorescence spectra approved a good discrimination of Emmental cheeses made from raw milk and those produced from thermised milk, which were not obtained by the other tow techniques (Figure 23.4). The authors concluded that NIR as well as FT-MIR could be used as fingerprint that allows the identification of Emmental cheeses according to their geographic origins and production conditions. However, in this study, only the tryptophan fluorescence spectra were acquired on the spectra and it would be interesting to compare the above-mentioned spectroscopic techniques with the vitamin A spectra, which were found to be the valuable tools for the evaluation of the quality

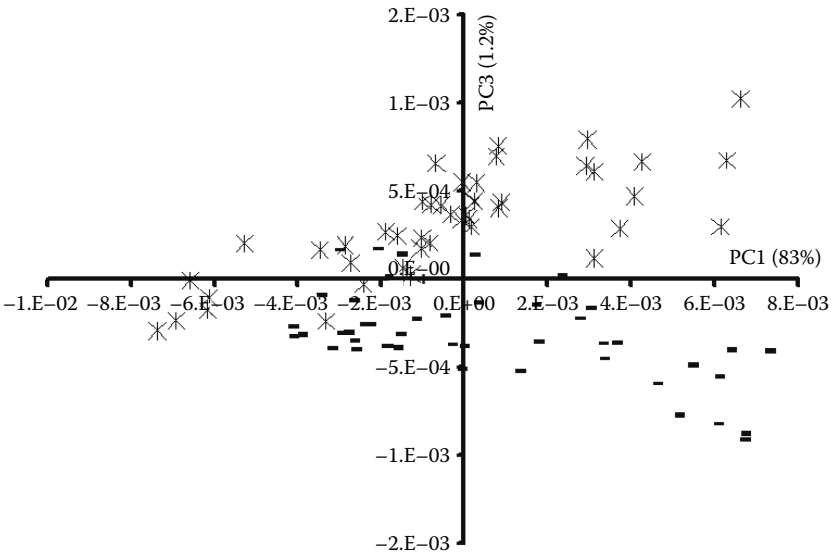


Figure 23.4 PCA is similarity map determined by principal components 1 (PC1) and 2 (PC2) for the tryptophan spectra of French Emmental cheeses made from raw (*) and thermised (–) milks.

© 2011 by Taylor and Francis Group, LLC

and identity of cheeses [54]. Thus, a total of 74 Emmental cheeses, produced during the summer, originating from six countries, were analyzed by both FT-MIR and FFFS [93]. The best results were obtained with vitamin A fluorescence spectra since 93.9% and 90.5% of the calibration and validation spectra, respectively, were correctly classified. One of the main conclusions of this study was that vitamin A fluorescence spectra might be considered as a promising probe for the reliable evaluation of Emmental cheese origin.

In order to determine the geographic origin of Emmental cheeses independently of their manufacture periods, concatenation technique was applied [94]. A total of 163 Emmental cheeses produced in winter ($n = 91$) and summer ($n = 72$) periods were investigated by the MIR and FFFS. Correct classification of 89% and 76.7% was observed for the calibration and validation samples, respectively. The authors reported that although this statistical technique did not allow 100% correct classification for all the groups, the obtained results could be considered as promising given the significant effect of the season on the quality of investigated cheeses. These results were confirmed after by the same research group on milk samples originating from different geographical origin in France by using the same statistical technique (Figure 23.5) [95].

The same research group continued this work and assessed the feasibility of discriminating the manufacturing process and sampling zone of 10 traditional M1 ($n = 5$) and M2 ($n = 5$) soft cheeses produced from raw milk, and five other stabilized M3 ($n = 5$) manufactured from pasteurized milk using the techniques mentioned earlier. References [96,97] provide an apt comparison of the three spectroscopic techniques used on the same cheese samples.

Regarding the FT-MIR spectra, the percentage of samples correctly classified into six groups (three for external and three for central zones) following FDA was 64.8% and 33.3%, respectively, for the calibration and validation sets [96]. Better classification was obtained from the VIS-NIR spectra where the corresponding results were 85.2% and 63.2%. However, the best results were obtained with vitamin A spectra since 91.8% and 80.6% of correct classification was obtained for the calibration and validation data sets, respectively in agreement with previous

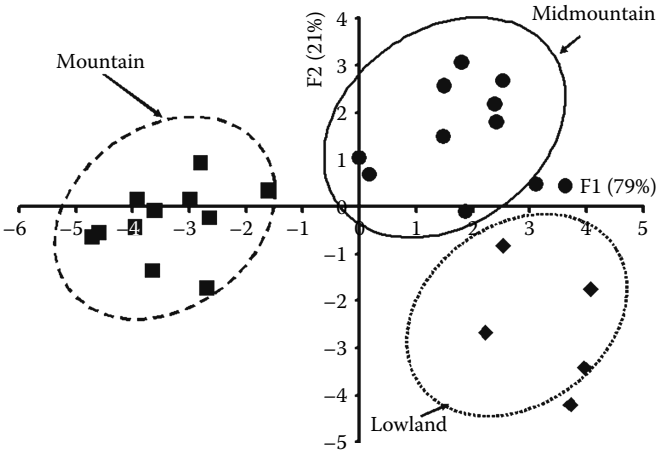


Figure 23.5 DA similarity maps determined by discriminant factors 1 and 2. FDA performed on the first 20 concatenated PC of the PCA performed on the fluorescence spectral data of the investigated: milks produced in lowland (♦), milks produced in mid-mountain (●), and milks produced in mountain (■) regions.

© 2011 by Taylor and Francis Group, LLC

findings reporting that vitamin A was a good probe for discriminating eight varieties of soft cheeses since 96% and 93% for the calibration and validation samples, respectively [54]. The above-mentioned papers outlined that although many papers were published in the area of cheese authenticity using FT-MIR spectroscopic techniques, both NIR and FFFS spectroscopies still more accurate tool in this area. The obtained results confirmed previous findings reporting the superiority of FFFS to FT-MIR for determining the geographic origin of Gruyère cheeses produced at different altitudes by using different manufacturing processes [92,93]. Karoui et al. [93] overcame some of these difficulties of the MIR technique by concentrating on a particular wavelength range. In assessing the potential of FT-MIR for the determination of the geographical origin of Gruyère cheeses, the FT-MIR results were found to be comparable to the FFFS results, giving corresponding correct classification of 90.5% and 90.9% within the 3000–2800 cm^{-1} and 1500–900 cm^{-1} spectral regions, respectively. As pointed out, the results obtained from FFFS were still superior to those obtained from FT-MIR, but by concentrating on some wavelength range in FT-MIR, a closer comparison was achieved. A good example of how wavelength selections leads to favorable results was outlined by Picque et al. [98] who obtained a correct classification of 93% by using the reduced wavelength range of 1050–1800 cm^{-1} in the FT-MIR region.

As illustrated earlier, most of the studies have utilized NIR, FT-MIR, and FFFS for determining the geographic origin of dairy products. However, other spectroscopic techniques have also demonstrated their high potential for determining the identity of dairy products. Renou et al. [99] used O and H isotopic ratios to differentiate between milks produced in plains (altitude 200 m) from those produced in mountains (altitude 1100 m). Their studies showed that milk enrichments differed significantly between sites for both ^{18}O and ^{2}H. On the plains, the ^{18}O enrichments were significantly higher for grazing cows than those fed on maize silage or hay. However, for the latter two diets, no significant differences were observed in $\delta^{18}O$ or $\delta^{2}H$. In another study, Manca et al. [100] applied PCA to the $^{13}C/^{12}C$ and $^{15}N/^{14}N$ of casein and a good discrimination was found according to the origin of cheeses. These findings were fully supported, recently, by Pillonel et al. [101] who attempted to discriminate European Emmental cheeses using different stable isotope ratios. Finnish and French cheeses were well separated using $\delta^{13}C$, $\delta^{15}N$, $\delta^{2}H$, $\delta^{87}Sr$-values. However, cheeses from Switzerland, Allgäu, and Vorarlberg were found to be similar. The obtained results confirmed previous findings of the same research group Rossmann et al. [102] outlining that stable isotope analysis succeeded to determine the geographic origin of butter originating from different geographic origins. The authors concluded that this technique could be a very potent tool with which to solve the problem of butter origin assignment.

However, the stable isotope approach also has some important constraints. Results obtained from stable isotope must be based on uniform environment features (e.g., climate, altitude, and distance from oceans) allowing few or no differences in isotopic ratios of the dairy products. Therefore, dairy products from animals originating from different, but climatically or geologically similar areas might have an identical isotopic signature. In addition, Ritz et al. [103] demonstrated that the breed of cows could influence the isotopic enrichment of milk, even in circumstances where the food and water consumed are similar.

The accuracy of ^{13}C NMR to differentiate cows' milk from buffaloes' milk was outlined by Andreotti et al. [104]. In their study, although a relatively low number of milk samples was studied, a good discrimination between the investigated milks was achieved following the application of PCA to the 10 NMR parameters.

© 2011 by Taylor and Francis Group, LLC

23.4 Conclusion

The quality control measurements of dairy products could be determined by several analytical techniques as presented in this chapter. However, spectroscopic techniques were demonstrated to be more rapid than traditional techniques, which needs skilled operators. FFFS, FT-MIR, and NIR, among other spectroscopies were demonstrated to be more suited to industrial applications than the traditional techniques. The potential of these technologies for compositional, ripening stage, rheological, and process monitoring applications at laboratory scale is also well documented. However, to date, there is no feasible ideal method for all purposes. An accurate determination of the quality and/or identity of dairy product seems feasible only when a combination of all parameters is applied. Indeed, the results illustrated in this chapter showed that the methodology of coupling different spectroscopic techniques by using appropriate chemometric tools enabled better discrimination of dairy products according to their geographical origin and ripening time. These techniques provide fingerprints of dairy products, which by comparison with authentic samples can be used to detect certain fraudulent practices and to authenticate the geographical origin. They can also provide an efficient means of enforcing the restricted rules associated with PDO-labeled products.

The equipment manufacturers are likely to put renewed emphasis on developing online instrumentation to facilitate improved process monitoring of cheese quality during manufacture. Thus, ready transfer of these techniques especially NIR and FFFS to the dairy plants as either on- or in-line methods is already possible. This transfer should increase the understanding of manufacturers of constituents that determine food texture and may allow them devising a structure engineering of cheese.

References

1. Downey, G. Authentication of food and food ingredients by near infrared spectroscopy, *J. Near Infrared Spectrosc*., 4, 47, 1996.
2. Karoui, R. and De Baerdemaeker, J. A review of the analytical methods coupled with chemometric tools for the determination of the geographical origin of dairy products. *Food Chem*., 102, 641, 2007.
3. Guinot-Thomas, P., Al Ammoury, M., and Laurent, L. Effects of storage conditions on the composition of raw milk. *Int. Dairy J*., 5, 211, 1995.
4. Bugaud, C. et al. Influence of the nature of alpine pastures on plasmin activity, fatty acid and volatile compound composition of milk. *Lait*, 81, 401, 2001.
5. Bugaud, C. et al. Relationships between Abondance cheese texture and that of milk produced by cows grazing different types of pastures. *Lait*, 81, 593, 2001.
6. Pillonel, L. et al. Geographic origin of European Emmental. Use of discriminant analysis and artificial neural network for classification purposes. *Int. Dairy J*., 15, 557, 2005.
7. Millán, R. et al. Application of discriminant analysis to physico-chemical variables for characterizing Spanish cheeses. *Food Chem*., 55, 189, 1996.
8. Maâmouri, O. et al. Mid infrared attenuated total reflection spectroscopy as a rapid tool to assess the quality of Sicilo-Sarde ewe's milk during the lactation period after replacing soybean meal with scotch bean in the feed ration. *Food Chem*., 106, 361, 2008.
9. Zaïdi, F. et al. Front face fluorescence spectroscopy as a rapid and non-destructive tool for differentiating between Sicilo-Sarde and Comisana ewe's milk during lactation period: A preliminary study. *Food Bioprocess Technol*., 1, 143, 2008.
10. O'Shea, B.A., Uniacke-Lowe, T., and Fox, P.F. Objective assessment of Cheddar cheese quality. *Int. Dairy J*., 6, 1135, 1996.

© 2011 by Taylor and Francis Group, LLC

11. Pripp, A.H. et al. Comparison of the biochemical characteristics of three Norwegian cheese varieties using multivariate statistical analysis. *Milchwissenschaft*, 54, 558, 1999.
12. Pripp, A.H. et al. Multivariate statistical analysis of peptide profiles and free amino acids to evaluate effects of single-strain starters on proteolysis in miniature Cheddar-type cheeses. *Int. Dairy J.*, 9, 473, 1999.
13. Ferreira, I.M.P.L.V.O. and Caçote, H. Detection and quantification of bovine, ovine and caprine milk percentages in protected denomination of origin cheeses by reversed-phase high-performance liquid chromatography of beta-lactoglobulins. *J. Chromatogr.*, 1015, 111, 2003.
14. Bara-Herczegh, O., Horváth-Almássy, K., and Őrsi, F. Application of multivariate methods to identify the indices of secondary proteolysis for Trappist cheese maturity and quality. *Eur. Food Res. Technol.*, 214, 516, 2002.
15. Frau, M. et al. Evolution of free amino acid content during ripening of Mahon cheese. *Food Chem.*, 60, 651, 1997.
16. Salles, C. et al. Evaluation of taste compounds in water-soluble extract of goat cheeses. *Food Chem.*, 68, 429, 2000.
17. Viallon, C. et al. Transfer of monoterpenes and sesquiterpenes from forages into milk fat. *Lait*, 80, 635, 2000.
18. Fernandez, C. et al. Characterization of milk by analysis of its terpene fractions. *Int. J. Food Sci. Technol*. 38, 445, 2003.
19. Collomb, M. et al. Composition of fatty acids in cow's milk fat produced in the lowlands, mountains and highlands of Switzerland using high-resolution gas chromatography. *Int. Dairy J.*, 12, 649, 2002.
20. Bosset, J.O. et al. Comparison of some highland and lowland Gruyère type cheese of Switzerland: A study of their potential PDO/AOC/AOP characteristics. Authenticity and adulteration of food—The analytical approach. *Proc. Eur. Food Chem*., 220, 395, 1997.
21. Cornu, A. et al. Terpene profiles in Cantal and Saint-Nectaire-type cheese made from raw or pasteurised milk. *J. Sci. Food Agric*., 85, 2040, 2005.
22. Pillonel, L. et al. Analytical methods for the determination of the geographic origin of Emmental cheese: Volatile compounds by GC/MS-FID and electronic nose. *Eur. Food Res. Technol*., 216, 179, 2003.
23. Shoemaker, Ch.F. et al. Rheological characterization of dairy products. *Food Technol*., January, 98, 1992.
24. Ak, M.M. and Gunasekaran, S. Stress–strain curve analysis of Cheddar cheese under uniaxial compression. *J. Food Sci*., 57, 1078, 1992.
25. Jaros, D. et al. Effect of water addition on composition and fracture properties of Emmental cheese. *Lait*, 77, 467, 1997.
26. Gryzowska, A. and Tuszynsky, W. Measurement of relative milk viscosity as criterion of analysis of its physical structure. *Technol. Zywnosci*, 1, 25, 1973.
27. Jeurnink, T.J.M. and DeKruif, K.G. Changes in milk on heating: Viscosity measurements. *J. Dairy Res*., 60, 139, 1993.
28. Biliaderis, C.G., Khan, M.M., and Blank, G. Rheological and sensory properties of yogurt from skim milk and ultrafiltered retentates. *Int. Dairy J*., 5, 311, 1992.
29. Rhom, H. and Kovac, A. Effects of starter cultures on linear viscoelastic and physical properties of yogurt gels. *J. Text. Stud*., 25, 311, 1994.
30. Rönnegård, E. and Dejmek, P. Development and breakdown in yoghurt studied by oscillatory rheological measurements. *Lait*, 73, 371, 1993.
31. Vlahopoulou, I. and Bell, A.E. The application of oscillatory testing to bovine and caprine yoghurt gel systems. In *Rheology of Food, Pharmaceutical and Biological Materials with General Rheology*, Carter, R.E. Ed., Elsevier, London, pp. 331, 1990.
32. Köksoy, A. and Kiliç, M. Effects of water and salt level on rheological properties of ayran, a Turkish yoghurt drink. *Int. Dairy J*., 13, 835, 2003.

© 2011 by Taylor and Francis Group, LLC

33. Dixon, B.D. and Parekh, J.V. Use of the cone penetrometer for testing the firmness of butter. *J. Text. Stud*., 10, 421, 1979.
34. Raphaelides, S.N., e al. Ripening effects on the rheological behaviour of Halloumi cheese. *J. Food Eng*. 76, 321, 2005.
35. Karoui, R., Laguet, A., and Dufour, E. Interest of fluorescence spectroscopy for the investigation of cheese melting—Correlation with rheology characteristics. *Lait*, 83, 251–264.
36. Karoui, R. and Dufour, E. Dynamic testing rheology and fluorescence spectroscopy investigations of surface to centre differences in ripened soft cheeses. *Int. Dairy J*., 13, 973, 2003.
37. Martens, M. A philosophy for sensory science. *Food Qual. Pref*., 10, 233, 1999.
38. Martens, M. and Martens, H. *Multivariate Analysis of Quality*. John Wiley and Sons, Chichester, U.K., 2001.
39. Wormbs, G. et al. The use of design of experiment and sensory analysis as tools for the evaluation of production methods for milk. *Chem. Intell. Lab. Syst*., 73, 67, 2004.
40. Horimoto, Y. and Nakai, S. Classification of pasteurized milk using principal component similarity analysis of off-flavours. *Food Res. Int*., 31, 279, 1998.
41. Quinones, H.J., Barbano, D.M., and Phillips, L.G. Influence of protein standardization by ultrafiltration on the viscosity, color, and sensory properties of 2% and 3.3% milks. *J. Dairy Sci*., 81, 884, 1998.
42. Quinones, H.J., Barbano, D.M., and Phillips, L.G. Influence of protein standardization by ultrafiltration on the viscosity, color, and sensory properties of skim and 1% milk. *J. Dairy Sci*., 80, 3142, 1997.
43. Lebecque, A. et al. Delineation of the texture of Salers cheese by sensory analysis and physical methods. *Lait*, 81, 609–623.
44. Ritvanen, T. et al. Sensory evaluation, chemical composition and consumer acceptance of full fat and reduced fat cheeses in the Finnish market. *Food Qual. Pref*., 16, 479, 2005.
45. Payne, F.A., Hicks, C.L., and Sheng, P. Predicting optimal cutting time of coagulating milk using diffuse reflectance. *J. Dairy Sci*., 76, 48, 1993.
46. O'Callaghana, D.J., O'Donnellb, C.P., and Paynec, F.A. On-line sensing techniques for coagulum setting in renneted milks. *J. Food Eng*., 43, 155, 2000.
47. McMahon, D.J., Brown, R.J., and Ernstrom, C.A. Enzymic coagulation of milk casein micelles. *J. Dairy Sci*., 67, 745, 1984.
48. Payne, F.A. et al. Fibre optic sensor for predicting the cutting time of coagulating milk for cheese production. *Trans. ASAE*, 36, 841, 1993.
49. Laporte, M.F., Martel, R., and Paquin, P. The near-infrared optic probe for monitoring rennet coagulation in cow's milk. *Int. Dairy J*., 8, 659, 1998.
50. Guillemin, H. et al. An optical method to monitor casein particle size distribution in whey. *Lait*, 86, 359, 2006.
51. Fagan, C.C. et al. Development of a light scatter sensor technology for on-line monitoring of milk coagulation and whey separation. *J. Food Eng*., 83, 61, 2007.
52. Fagan, C.C. et al. On-line prediction of cheese making indices using backscatter of near infrared light. *Int. Dairy J*., 18, 120, 2008.
53. Fagan, C.C. et al. Novel on-line sensor technology for continuous monitoring of milk coagulation and whey separation in cheese making. *J. Agric. Food Chem*., 55, 8836, 2007.
54. Herbert, S. et al. Fluorescence spectroscopy investigations of acid- and rennet-induced milk coagulation of milk. *J. Dairy Sci*., 82, 2056, 1999.
55. Dufour, E. and Riaublanc, A. Potentiality of spectroscopic methods for the characterisation of dairy products. I. Front-face fluorescence study of raw, heated and homogenised milks. *Lait*, 77, 657, 1997.
56. Kulmyrzaev, A., Levieux, D., and Dufour, E. Front-face fluorescence spectroscopy allows the characterization of mild heat treatment applied to milk. Relations with the denaturation of milk proteins. *J. Agric. Food Chem*., 53, 502, 2005.

© 2011 by Taylor and Francis Group, LLC

57. Boubellouta, T. and Dufour E. Mild-heating and acidification effects on the molecular structure of milk components as investigated by synchronous front-face fluorescence spectroscopy coupled with parallel factors (PARAFAC) analysis. *Appl. Spectrosc*., 62, 490, 2008.
58. Schamberger, G.P. and Labuza, T.P. Evaluation of front-face fluorescence for assessing thermal processing of milk. *J. Food Sci*., 71, 69, 2006.
59. Liu, X. and Metzger, L.E. Application of fluorescence spectroscopy for monitoring changes in nonfat dry milk during storage. *J. Dairy Sci*., 90, 24, 2007.
60. Feinberg, M. et al. Evaluation of tracers for the authentication of thermal treatments of milks. *Food Chem*., 98, 188, 2006.
61. Martín-del-Campo, S.T. et al. Middle infrared spectroscopy characterization of ripening stages of camembert-type cheese. *Int. Dairy J*., 17, 835, 2007.
62. Martín-del-Campo, S.T. et al. Evaluation of chemical parameters in soft mold-ripened cheese during ripening by mid-infrared spectroscopy. *J. Dairy Sci*., 90, 3018, 2007.
63. Downey, G. et al. Prediction of maturity and sensory attributes of Cheddar cheese using near-infrared spectroscopy. *Int. Dairy J*., 15, 701, 2005.
64. Burns, D.A. and Ciurczak, E.W. *Handbook of Near Infrared Analysis*. Dekker, New York, 1992.
65. Cattaneo, T.M.P. et al. Application of FT-NIR and FT-IR spectroscopy to study the shelf-life of Crescenza cheese. *Int. Dairy J*., 15, 693, 2005.
66. Dufour, E. et al. Phase transition of triglycerides during semi-hard cheese ripening. *Int. Dairy J*., 10, 81, 2000.
67. Mazerolles, G. et al. Infrared and fluorescence spectroscopy for monitoring protein structure and interaction changes during cheese ripening. *Lait*, 81, 509, 2001.
68. Mazerolles, G. et al. Chemometric methods for the coupling of spectroscopic techniques and for the extraction of the relevant information contained in the spectral data tables. *Chem. Intell. Lab. Syst*, 63, 57, 2002.
69. Karoui, R., Dufour, E., and De Baerdemaeker, J. Monitoring the molecular changes by front face fluorescence spectroscopy throughout ripening of a semi-hard cheese. *Food Chem*. 104, 409, 2007.
70. Picque, D., Lefier, D., and Grappin, R. Monitoring of fermentation by infrared spectrometry: Alcoholic and lactic fermentation. *Anal. Chim. Acta*, 279, 67, 1993.
71. Kulmyrzaev, A. et al. Investigation at the molecular level of soft cheese quality and ripening by infrared and fluorescence spectroscopies and chemometrics—Relationships with rheology properties. *Int. Dairy J*., 15, 669, 2005.
72. Karoui, R., Dufour, E., and De Baerdemaeker, J. Common components and specific weights analysis: A tool for monitoring the molecular structure of semi-hard cheese throughout ripening. *Anal. Chim. Acta*, 572, 125, 2006.
73. De Angelis Curtis, S. et al. Amino acid profile in the ripening of Grana Padano cheese: A NMR study. *Food Chem*., 71, 495, 2000.
74. Kuo, M.I. et al. Nuclear Magnetic Resonance study of water mobility in Pasta Filata ad non-Pasta Filata Mozzarella. *J. Dairy Sci*., 84, 1950, 2006.
75. Filho, P.A.D.A. and Volery, P. Broad-based versus specific NIRS calibration: Determination of total solids in fresh cheeses. *Anal. Chim. Acta*, 544, 82, 2005.
76. Blaquez, C. et al. Prediction of moisture, fat and inorganic salts in processed cheese by near infrared reflectance spectroscopy and multivariate data analysis. *J. Near Infrared Spectrosc*., 12, 149, 2004.
77. Blaquez, C. et al. Modelling of sensory and instrumental texture parameters in processed cheese by near infrared reflectance spectroscopy. *J. Dairy Res*., 73, 58, 2006.
78. McKenna, D. Measuring moisture in cheese by near infrared absorption spectroscopy. *J. AOAC Int*., 84, 623, 2001.
79. Lynch, J.M. and Barbano, D.M. Evaluation of commercially available milk powder for calibration of mid-infrared analyzers. *J. AOAC Int*., 78, 1219, 1995.
80. Sørensen, L.K., Lund, M., and Juul, B. Accuracy of Fourier transform infrared spectrometry in determination of casein in dairy cow's milk. *J. Dairy Res*., 70, 445, 2003.

© 2011 by Taylor and Francis Group, LLC

81. Etzion, Y. et al. Determination of protein concentration in raw milk by mid-infrared Fourier transform infrared/attenuated total reflectance spectroscopy. *J. Dairy Sci*., 87, 2779, 2004.
82. Iñón, F.A., Garrigues, J.M., and de la Guardia, M. Nutritional parameters of commercially available milk samples by FTIR and chemometric techniques. *Anal. Chim. Acta*, 513, 401, 2003.
83. Karoui, R. et al. A comparison and joint use of two spectroscopic methods for the determination of some parameters in European Emmental cheeses. *Eur. Food Res. Technol*., 223, 44, 2006.
84. Karoui, R. et al. Mid infrared spectrometry: A tool for the determination of chemical parameters of Emmental cheeses produced during winter. *Lait*, 86, 83, 2006.
85. Karoui, R. et al. A comparison and joint use of NIR and MIR spectroscopic methods for the determination of some chemical parameters in soft cheeses at external and central zones. *Eur. Food Res. Technol*., 223, 363, 2006.
86. Karoui, R. et al. Utilisation of front face fluorescence spectroscopy for the determination of some chemical parameters in soft cheeses at external and central zones. *Lait*, 86, 155, 2006.
87. Karoui, R. and Dufour, E. Prediction of the rheology parameters of ripened semi-hard cheeses using fluorescence spectra in the UV and visible ranges recorded at a young stage. *Int. Dairy J*., 16, 1490, 2006.
88. Karoui R., De Baerdemaeker, J., and Dufour, E. Utilisation of front face fluorescence spectroscopy as a tool for the prediction of some chemical parameters and the melting point of semi-hard and hard cheeses: A preliminary study. *Eur. Food Res. Technol*., 226, 1119, 2008.
89. Woodcock, T. et al. Application of near and mid-infrared spectroscopy to determine cheese quality and authenticity. *Food Process Technol*., 1, 117, 2008.
90. Pillonel, L. et al. Analytical methods for the determination of the geographic origin of Emmental cheese. Mid and near-infrared spectroscopy. *Eur. Food Res. Technol*., 216, 174, 2003.
91. Karoui, R. et al. Determination of the geographic origin of Emmental cheeses by combining infrared and fluorescence spectroscopies. *Int. Dairy J*., 15, 287, 2005.
92. Karoui, R. et al. Monitoring the geographic origin of both experimental French Jura hard cheeses and Swiss Gruyère and l'etivaz PDO cheeses using mid-infrared and fluorescence spectroscopies. *Int. Dairy J*., 15, 275, 2005.
93. Karoui, R. et al. Fluorescence and infrared spectroscopies: A tool for the determination of the geographic origin of Emmental cheeses manufactured during summer. *Lait*, 84, 359, 2004.
94. Karoui, R. et al. Determining the geographic origin of Emmental cheeses produced during winter and summer using a technique based on the concatenation of MIR and fluorescence spectroscopic data. *Eur. Food Res. Technol*., 219, 184, 2004.
95. Karoui, R., Martin, B., and Dufour, E. Potentiality of front-face fluorescence spectroscopy to determine the geographic origin of milks from Haute-Loire department (France). *Lait*, 85, 223, 2005.
96. Karoui, R. et al. Feasibility study of discriminating the manufacturing process and sampling zone in ripened soft cheeses using attenuated total reflectance MIR and fiber optic diffuse reflectance VIS-NIR spectroscopy. *Food Res. Int*. 39, 588, 2006.
97. Karoui, R., De Baerdemaeker, J., and Dufour, E. A comparison and joint use of mid infrared and fluorescence spectroscopic methods for differentiating between manufacturing process and sampling zones of ripened soft cheeses. *Eur. Food Res. Technol*., 226, 861, 2008.
98. Picque, D. et al. Discrimination of European Emmental cheese by midinfrared spectroscopy. *Proceedings of IDF Symposium on Cheese: Ripening, Characterisation and Technology*, Prague, Czech Republic, 21–25 March 2004.
99. Renou, J.P. et al. Characterization of animal products according to geographic origin and feeding diet using nuclear magnetic resonance and isotope ratio mass spectrometry: Cow milk. *Food Chem*., 85, 63, 2004.
100. Manca, G. et al. Characterization of the geographical origin of Pecorino Sardo cheese by casein stable isotope ($^{13}C/C^{12}$ and $^{15}N/^{14}N$) ratios and free amino acid ratios. *J. Agric. Food Chem*., 49, 1404, 2001.
101. Pillonel, L. et al. Stable isotope ratios, major, trace and radioactive elements in Emmental cheeses of different origins. *Lebensm-Wissenschaft und-Technologie*, 36, 615, 2003.

© 2011 by Taylor and Francis Group, LLC

102. Rossmann, A. et al. The potential of multielement stable isotope analysis for regional origin assignment of butter. *Eur. Food Res. Technol*., 211, 32, 2000.
103. Ritz, P. et al. Milk characterization: Effect of the breed. *Food Chem*., 91, 521, 2005.
104. Andreotti, G. et al. Milk identification of different species: 13C-NMR Spectroscopy of triacylglycerols from cows and buffaloes' miles. *J. Dairy Sci*., 83, 2432, 2000.

© 2011 by Taylor and Francis Group, LLC

Index

A

Allo-Kramer Shear (AKS), 123–124
Analytical flavor assessment, dairy products
  electronic nose and tongue, 402–403
  fingerprint acquisition, 400–402
  gas chromatography (*see* Gas chromatography)
Androstenone, 57–58
Apple fiber, 111
Aroma extract dilution analysis (AEDA), 244
Artificial quality index (AQI), 204, 236
Atmospheric pressure chemical ionization mass spectrometry (APCI-MS), 360–361, 363–365

B

Bacon, flavor analysis
  aroma compounds, 135–136
  chemical compounds, 135
  n-3 polyunsaturated fatty acids, 136
  pork belly thickness, 136
  vs. uncured bacon, 135

C

Cesia, 4
Cheese
  composition and rheology
    correlation coefficient (R^2), 425
    near infrared (NIR) reflectance spectroscopy, 423–424
  flavor, 363–365
    citrate conversion, 374–375
    lactose fermentation, 374–375
    lipolysis and catabolism, fatty acids, 378–380
    proteolysis, 374–375
  processing, 327, 329
  ripening
    cheese authenticity, 425–428
    cheese composition and rheology, 423–425
    coagulation control, 419–421
    common component and specific weights analysis (CCSWA), 422–423
    degree determination, 421
    gas chromatographic techniques, 416–417
    heat treatment control, 419–421
    liquid chromatographic techniques, 416
    molecular level structural information, 421
    physicochemical analyses, 414–416
    protein hydrolysis, 422
    rheological techniques, 417–418
    sensory analysis, 418
    sensory attributes, 423–425
    syneresis control, 419–421
  texture analysis, 345
CIELAB color coordinates, 6
Citrus fiber, 111–112
Clupea harengus, 305
Color characteristics
  dairy food
    color chart/color fan, 323–324
    computer vision, 324
    digital scanning, 324
    HPLC, pigments, 324
    image analysis, 324
    postprocessing, 331–332
    practical applications, 324–331, 335–336
    quality control, 332–334
    spectral reflectance graph, 322–323
    tristimulus colorimetry, 322
    visible spectrophotometers, 321
    VNIR spectrophotometry, 321–322
  fish and seafoods
    aquaculture, 204–206
    Color Reader CR-10, 202
    fish mince, surimi, and surimi-based products, 207–211
    high-pressure processing, 207, 211, 219–221
    HunterLab MiniScan XE Plus 45/0 LAV spectrophotometer, 202–203
    novel method, 203–204
    processing effect, 207–211

© 2011 by Taylor and Francis Group, LLC

refrigerated and frozen storage, 207, 212–215
spectral color meter spectro-pen, 201–202
spectrophotometers, 202
thermal processing (heating and smoking), 207, 216–218
trichromatic colorimeters, 201–202
tristimulus colorimeter *vs*. spectrophotometers, 203
meat
color measurements (*see* Muscle-based foods, meat)
cooked meat, 87–89
processed meat
color attributes, 102
color measurement (*see* Processed meat)
space, 6–7
Combined hedonic aroma response method (CHARM), 255, 396
Commission Internationale de l'Eclairage (CIE), 200
Compression test
single compression test, 125
texture profile analysis (TPA)
Duncan's test results, 125–127
vs. WBS test, 127
Conjugated linoleic acid, 112
Cooked meat
color, 87–89
measurement, 88
myoglobin, 88
pigments extraction, 88–89
flavor, 87
amino acids, 93
fatty acids, 93
headspace gas chromatography, 95
Maillard reaction, 93–94
product appearance, 95
PUFAs, 95
rancid flavor, 94
smell impression, 92
smell perception, 93
storage, 95
Strecker reactions, 94
volatile components, 93
sensory descriptors
descriptor development, 153
flavor descriptors, 158–162
flavor profile (FPM), 148–149
free choice profiling (FCP), 151
generic descriptive analysis, 151
odor, 150, 164–165
panel selection, 152
quantitative descriptive analysis (QDA), 150
quantitative flavor profiling, 151
sensory method, 148
spectrum descriptive analysis, 150
texture descriptors, 153–159
texture, 88, 93 (*see also* Texture profile analysis (TPA))
Crustaceans, 304
Cured meat products, flavor, *see also* Dry-cured meat products
analysis
odorants evaluation, 134
volatile extraction techniques, 132–133
bacon
aroma compounds, 135–136
chemical compounds, 135
n-3 polyunsaturated fatty acids, 136
pork belly thickness, 136
vs. uncured bacon, 135
cooked ham, 137
dry-cured meat products (*see* Dry-cured meat products, flavor)
frankfurter, 137
precursors, 132
roast beef, 137–138
wet curing, 132

D

Dairy products
color analysis
color chart/color fan, 323–324
computer vision, 324
digital scanning, 324
HPLC, pigments, 324
image analysis, 324
postprocessing, 331–332
practical applications, 324–331, 335–336
quality control, 332–334
spectral reflectance graph, 322–323
tristimulus colorimetry, 322
visible spectrophotometers, 321
VNIR spectrophotometry, 321–322
flavor (*see also* Analytical flavor assessment, dairy products)
cheese, 363–365
custard, 363
diffusion measurement, 356–359
distortion, 356
extraction techniques, 387–389
flavor transfer, 359–360
gel model systems, 360–361
mastication, 356
mechanistic approach, 356
off-flavors, 406–408
sensorial analysis, 403–406
Stokes–Einstein law, 355
yoghurts, 361–363
practical applications
β-carotene concentration, 325
butter, 326–327
cheese browning, pizza, 329
cheese making, 327

© 2011 by Taylor and Francis Group, LLC

food composition, modification, 328
milk color measurement, 324
Mozzarella, whiteness, 329
soft cheese surface, microflora role, 329–331
ultrafiltration/high-pressure, 327–328
quality, cheese ripening
cheese authenticity, 425–428
cheese composition and rheology, 423–425
cheese ripening, 421–423
coagulation control, 419–421
gas chromatographic techniques, 416–417
heat treatment control, 419–421
liquid chromatographic techniques, 416
physicochemical analyses, 414–416
rheological techniques, 417–418
sensory analysis, 418
sensory attributes, 423–425
syneresis control, 419–421
textural variety, 354–355
texture (*see* Texture)
Degree of solidity, 235
Descriptive sensory test, 286
Discriminative sensory test, 286
Dry-cured ham
color measurement, 108–109
flavor, 138
sensory descriptors
acceptability tests, 184, 190
appearance descriptors, 191–192
application, sensory profiling methods, 184–187
flavor descriptors, 184, 190
processing, 184
references used in sensory evaluation, 184, 188–189
sensations and texture descriptors, 191
taste descriptor, 191
Dry-cured meat products, *see also* Dry-cured ham; Dry-fermented sausages
attribute-specific scaling, 176
color measurement
dry-cured ham, 108–109
dry-cured sausages, 106–108
flavor, 132
dry-cured ham, 138
dry curing, 131–132
sensory descriptors
attribute-specific scaling, 176
dry-cured ham, 184–192
dry-fermented sausages, 176–183
sensory profiling methods, 174–175
Dry-fermented sausages
flavor
detection frequency method, 142
distillation technique, 141
headspace analysis, 138, 141
odor-active compounds, 140–141
sensory descriptors
acceptability and preference tests, 176, 182
appearance descriptors, 183
application, sensory profiling methods, 176–179
attribute references, 176, 180–181
flavor descriptors, 176, 183
sensations and texture descriptors, 183
taste descriptors, 182
Dual energy x-ray absorptiometry (DEXA) imaging, 29
Dynamic headspace analysis, 42–43
Dynamic headspace dilution assay (DHDA), 399–400

E

Elastography, 29–30
Electrognathography (EGN), 29
Electromyography (EMG), 29
Electronic noses, 165
Entire color index (ECI), 204
European consumer expectations, 65–66

F

Fermented dairy products, *see also* Cheese
cheese, flavor formation
citrate conversion, 374–375
lactose fermentation, 374–375
lipolysis and catabolism, fatty acids, 378–380
proteolysis, 374–375
pathways, 370
Fick's second law, 358
Finger test, 233
Fish and seafoods, *see also* Heat treated seafood
aroma
adsorption, 250–251
components, 253–255
compound identification, 244–245
electronic nose, 256
geosmin and 2-methylisoborneol analysis, 253
headspace analysis, 249–250
high vacuum distillation/solvent-assisted flavor evaporation, 249
pre-and postslaughter treatment, 245
sample preparation, 246
simultaneous distillation/extraction (SDE), 247–248
solid-phase microextraction (SPME), 251–252
solvent extraction, 246
steam distillation, 247
trimethylamine oxide breakdown product analysis, 253
vacuum steam distillation, 247
color measurement
aquaculture, 204–206
Color Reader CR-10, 202
fish mince, surimi, and surimi-based products, 207–211
high-pressure processing, 207, 211, 219–221

© 2011 by Taylor and Francis Group, LLC

HunterLab MiniScan XE Plus 45/0 LAV spectrophotometer, 202–203
novel method, 203–204
processing effect, 207–211
refrigerated and frozen storage, 207, 212–215
spectral color meter spectropen, 201–202
spectrophotometers, 202
thermal processing (heating and smoking), 207, 216–218
trichromatic colorimeters, 201–202
tristimulus colorimeter *vs*. spectrophotometers, 203
instrumental texture
compression test, 233–234
Kramer test, 231
myocommata, 230
puncture test, 232–233
quality index method (QIM), 230
stress relaxation test, 235–236
tension analysis, 233
test procedure and sample preparation, 230–231
texture measurement, quality assessment, 236–237
texture profile analysis (TPA), 234–235
viscoelastic methods, 235
Warner–Bratzler test, 231–232
quality index methods (QIM)
assessors, 273–275
demands, testing area, 272
Gadus morhua (cod), 268, 270–271
nonbiased sampling, 272
principles, 268
raw material, 276–277
relation to EU-scheme, 280–281
Salmo salar (salmon), 268–270
scheme setting and testing, 277–279
sessions, 273, 275
shelf life estimation, 275–277
validation, 279–280
sensory descriptors (*see* Sensory descriptors)
Fish shearing device (FSD), 232
Flash profile method, 151
Flavor, *see also* Volatile compound analysis
cheese
citrate conversion, 374–375
lactose fermentation, 374–375
lipolysis and catabolism, fatty acids, 378–380
proteolysis, 374–375
cooked meat, 87
amino acids, 93
fatty acids, 93
headspace gas chromatography, 95
Maillard reaction, 93–94
product appearance, 95
PUFAs, 95
rancid flavor, 94
smell impression, 92
smell perception, 93
storage, 95
Strecker reactions, 94
volatile components, 93
dairy products (*see also* Analytical flavor assessment, dairy products)
cheese, 363–365
custard, 363
diffusion measurement, 356–359
distortion, 356
extraction techniques, 387–389
flavor transfer, 359–360
gel model systems, 360–361
mastication, 356
mechanistic approach, 356
off-flavors, 406–408
sensorial analysis, 403–406
Stokes–Einstein law, 355
yoghurts, 361–363
fish and seafoods
components, 253–255
compound identification, 244–245
electronic nose, 256
extraction methods, 246–253
pre-and postslaughter treatment effect measurement, 245
sample preparation, 246
meat, 40
animal feeding system, 40
applications, 45
cooked meat, 40
grass feeding system, 41
sampling and identification (*see* Volatile compound analysis)
milk
heat treatment and storage, 371–372
light-induced flavor formation, 373
lipids, autoxidation, 372–373
package component migration, 373–374
processed meat
cured meat products (*see* Cured meat products, flavor)
volatile compound analysis, 132–134
Flavor dilution (FD) factor, 399–400, 403, 407
Flavor lexicons
flavor languages, 162–164
Spanish dry-cured sausage, 164
Flavor profile method (FPM), 148–149
Food-related lifestyle model, 66
Functional foods, 111–113

G

Gas chromatographic techniques, 416–417
Gas chromatography
dairy flavor investigation (*see also* Odor-activity assessment)
mass spectrometry, 391–392
peak enlargement phenomena, 390

© 2011 by Taylor and Francis Group, LLC

retention index methods, 391
signal *vs*. time graphic, 389
two-dimensional gas chromatography, 392–394
Gas chromatography coupled with mass spectrometry (GC/MS), 391–392
Gas chromatography–olfactometry (GC-O), 45, *see also* Odor-activity assessment
Gel model systems, 360–361
General procrustes analysis (GPA), 151
Good manufacturing practice (GMP), 276
Gustatory sense
saliva, 288
taste receptors, 287–288

H

Headspace analysis method, volatile compounds
dynamic headspace analysis, 42–43
static headspace sampling, 42
Headspace/direct gas chromatography-mass spectrometry (GC/MS), 165
Heat treated seafood
anatomy, 304–305
assessors, 307
handling, 306
Oncohynchus kisutch, 311
Oncorhynchus keta, 311
palate cleansers, 309
Penaeus vannamei, 312–313
principal component analysis, 312
sample preparation, 309–310
scales, 308
sensory attributes, 310
shellfish, 304
species *vs*. individuals, 305–306
test room, 307–308
High-performance liquid chromatography (HPLC), pigments, 324
High pressure liquid chromatography, 165
Hippoglossus hippoglossus, 311

I

Interesterified vegetable oils, 112

K

Kinesthesis, 287

L

Lipolysis and catabolism, fatty acids
enzymatic reduction, 380
lipid catabolism pathways, microorganisms, 378–379
Liquid chromatographic techniques, 416
Lycopene, 112

M

Magnetic resonance elastography (MRE), 30
Maillard reaction, 40, 160
Meat, *see also* Cooked meat
color measurements (*see* Muscle-based foods, meat)
flavor, 40
animal feeding system, 40
applications, 45
cooked meat, 40
grass feeding system, 41
sampling and identification (*see* Volatile compound analysis)
quality perception (*see* Quality perception, meat)
sensory descriptors (*see* Sensory descriptors)
texture (*see* Texture analysis)
Meat flavor deterioration (MFD), 161
Metallic sensation, 191
Milk
carotenoids, 325
color measurement, 324–325
flavor formation
heat treatment and storage, 371–372
light-induced flavor formation, 373
lipids, autoxidation, 372–373
package component migration, 373–374
raw milk, 325
MIRINZ tenderness probe, 25
MIT Denture tenderometer, 20
Mollusks, *see* Shellfish
Muscle-based foods, meat
color attributes
appearance, 4
pigments, 5
quality, 4–5
raw materials, 5
spatial properties, 4
color measurement
CIELAB color coordinates, 6
color space, 6–7
near-infrared analysis, 9–10
optical methods, 6
pigment extraction methods, 6
reflectance measurements, 7–9

N

Nasal impact frequency (NIF) profiles, 397–399
Natural color system (NCS®), 291
Near-infrared reflectance (NIR) spectroscopy, 9–10, 27
Nondestructive method, 275
Nondestructive shape profiling system, 29

O

Odor-activity assessment
gas chromatography-olfactometry (GC-O)

© 2011 by Taylor and Francis Group, LLC

aroma extraction dilution analysis (AEDA), 396
combined hedonic aroma response method (CHARM), 396
dynamic headspace dilution assay (DHDA), 399–400
nasal impact frequency (NIF) profiles, 397–399
regular and low-fat cheddar cheese, 404
surface of NIF (SNIF), 397–398
odor-activity value (OAV) concept, 403–404
recombined model systems, 404
Off-flavors, 406–408
Olive oil, 112
Oncohynchus kisutch, 311
Oncorhynchus keta, 311
OSME, 255
Overall sensory score, 275

P

Pale, soft, exudative (PSE) meat, 5
Pea fiber, 112
Penaeus vannamei, 312–313
Photoelectric color-measuring instruments, 201
Pigments, 5
extraction methods, 6
HPLC, 324
meat color, 88–89
Pleuronectes platessa, 268
Plum fiber, 111
Principal component analysis (PCA), 278, 415
Processed meat
color measurement
aging, 105
aperture size, 103–104
cooked meat products, 109–110
dry-cured meat products, 106–109
fresh meat products, 105–106
marination, 110–111
meat color, 104
reflectance spectroscopy, 102–103
slaughter, 104–105
cooked meat products (*see* Cooked meat)
flavor
cooked meat products (*see* Cooked meat)
cured meat products (*see* Cured meat products, flavor)
volatile compound analysis, 132–134
texture analysis, 121–122
compression test, 122–123
light reflectance, 128–129
meat textural parameters, 121
penetration, 124–125
shear test (*see* Shear test)
small deformation tests, 122, 128–129
tension, 127
torsion test, 127–128
Protected designation of origin (PDO), 325
Protected geographical indication (PGI), 325
Proteolysis
aromatic amino acids, catabolism, 377–378
branched-chain amino acids, metabolism, 376–377
methionine, catabolic pathways, 378
protein metabolic pathways, overview, 376–377
rate-limiting factor, 376
Proton-transfer reaction mass spectrometry (PTR-MS), 360
Puff test, 129
Punch and die test, 232

Q

Quality perception, meat
consumer expectations
assimilation, 64–65
assimilation–contrast, 65
contrast, 65
convenience, 66–67
European consumer expectations, 65–66
food-related lifestyle model, 66
generalized negativity, 65
intrinsic product characteristics, 67
perceived fat and purchase place, 65–66
product selection and evaluation, 64–65
gamma-radiation, 80–81
genetic factors, 77–78
ingredients and product preparation, 80–81
meat type
beef, 76–77
chicken, 75–76
goat, 77
pork, 76
nutritional value, 81
postmortem practices, 80
production and rearing condition, 78–80
quality quadrant, 62–63
sensory evaluation (*see* Sensory evaluation, consumer studies)
warmed-over flavor, 78–79
Quantitative descriptive analysis methods (QDA), 150
Quantitative flavor profiling (QFP) method, 151

R

Raman spectroscopy, 27
Repertory grid method (RGM), 151
Rhodocyclus gelatinosus supplementation, 5
Rice bran, 112
Rigor mortis, 306
Rye bran, 112

S

Salmo salar, 305
Screening and discrimination LC–DAD methods, 334–336

© 2011 by Taylor and Francis Group, LLC

Seafoods, *see* Fish and seafoods
Sensing devices, *see* Electronic noses
Sensory descriptors
  cooked meat products
    descriptor development, 153
    flavor descriptors, 158–162
    flavor profile (FPM), 148–149
    free choice profiling (FCP), 151
    generic descriptive analysis, 151
    odor, *150,* 164–165
    panel selection, 152
    quantitative descriptive analysis (QDA), 150
    quantitative flavor profiling, 151
    sensory method, 148
    spectrum descriptive analysis, 150
    texture descriptors, 153–159
  dry-cured meat products
    attribute-specific scaling, 176
    dry-cured ham, 184–192
    dry-fermented sausages, 176–183
    sensory profiling methods, 174–175
  meat
    contextual influences, 51–52
    cooked lamb muscle, 55–56
    endpoint temperature, 52–53
    fatty acid composition, 54
    flavor oxidation, beef, 56–57
    lamb loins, British *vs*. Spanish taste panels, 53–54
    lamb types/production systems, 54–55
    lipid oxidation, 56
    model systems, 57–58
    9-point hedonic scale, 51
    toughness/tenderness, 53
  seafood
    appearance, 291–292
    chemical/trigeminal sense, 288
    Gustatory sense, 287–288
    hearing sense, 288
    odor, 292–294
    olfactory sense, 287
    qualitative and quantitative part, 288–290
    salmon, sensory profiling, 290
    sensory analysis, 286
    taste/flavor, 292, 295–296
    texture, 296–298
    touch sense, 287
    visual sense, 286–287
  sensory profiling methods, 174–175
Sensory evaluation, consumer studies
  affective tests
    acceptance testing, 71
    consumer testing, 73–75
    preference, 71, 73
    qualitative and quantitative studies, 74–75
    sample preparation and presentation, 70
  in company, 67–68
  descriptive analysis
    applications, 70
    flavor and texture lexicons, 72–73
    instrumental data, 71
    methods, 71
  discriminative test, 70
  motivation guide lines, 70
  requester/client, 68
  sensory analyst, 68
  sensory panel, 68
  steps involved in, 69
  test area, 68–69
Sensory perception, 296
Shear test
  Allo-Kramer Shear (AKS), 123–124
  single compression test, 122–123
  Warner Bratzler Shear (WBS), 122–124
Shellfish, 304
Simultaneous distillation/extraction (SDE), aroma
  drawbacks, 248
  Likens–Nickerson apparatus, 247–248
  quantitative GC–olfactometry (GC–O) techniques (*see* Aroma extract dilution analysis)
Skatole, 57–58
Solid-phase micro extraction (SPME), 133
Solvent-assisted flavor evaporation apparatus, 249
Somesthesis, 287
Sonography, 28
Soy protein, 112
Spectrum descriptive analysis method, 150
Stable micro systems (SMS) device, 231
Static headspace analysis, 42
Stokes–Einstein law, 355
Stress relaxation test
  creep test, 235–236
  small amplitude oscillatory test, 236
Supercritical fluid extraction (SFE), 246
Surface of NIF (SNIF), 397–398

T

Tensipresser probe, 26
Textural profile method (TPM)
  definition, 149
  textural properties and popular nomenclature, 149–150
Texture analysis, 121–122, *see also* Compression test
  cooked meat (*see* Cooked meat)
  dairy foods
    butter, 345–346
    cheese, 345
    definition, 343
    factors affecting, 342–343
    sensory measurements, 347
    test procedure selection, 349–350
    texture profile analysis (TPA), 344–345

© 2011 by Taylor and Francis Group, LLC

uniaxial compression test, 345
viscosity measurement, 347–349
yogurt, 346–347
meat
digital texture analyzers, 21
elastography, 29–30
electromyography (EMG) and electrognathography (EGN), 29
image analysis, 28–29
isometric tension development, 26–27
near-infrared reflectance (NIR) spectroscopy, 27
needle arrays, 25–26
nondestructive deformation tests, 26
plumb bob, 26
Raman spectroscopy, 27
razor blade, 24
sharp and blunt blades, 21–24
sonoelasticity, 28
star and hollow probes, 26
ultrasonic technology, 28
Warner–Bratzler shear (WBS), 16–20
processed meat
compression test, 122–123
light reflectance, 128–129
meat textural parameters, 121
penetration, 124–125
shear test (*see* Shear test)
small deformation tests, 122, 128–129
tension, 127
torsion test, 127–128
Texture profile analysis (TPA)
cooked meat
adhesivity, 92
cohesivity, 91
compression test, 91
elasticity, 91
fibers, 92
hardness, 91
masticability, 92
pork meat, 92
touch sensation, 92
dairy foods, 344–345
processed meat
Duncan's test results, 125–127
vs. WBS test, 127
seafood, 296
Thiobarbituric acid reactive substances (TBARS), 160
Torry-scale, 278
Torsion test, 127–128
Trichromatic colorimeters, 201
Tristimulus colorimetry, 322
Two-dimensional gas chromatography, 392–394

U

Ultrasonics and sonoelasticity, 28
Unixial compression test, 344–345
UV–vis diode array spectrophotometer, 321

V

Video image scanning and analysis (VISA), 9
Viscosity measurement, dairy foods
capillary tube viscometer, 349
Newtonian fluids law, 347–348
rotational viscometers, 349
shear stress *vs*. shear rate
Newtonian fluids, 348
non-Newtonian fluids, 348
Visible and near-infrared reflectance (VNIR) spectrophotometry, 321–322
Volatile compound analysis
meat
applications, 45
cooked meat, 40
dynamic headspace sampling, 42–43
extraction—GC-O, 45
identification, GC-O, 44
static headspace sampling, 42
in vitro sampling, 43
in vivo sampling, 43–44
processed meat
aroma-active components, 133–134
extraction technique, 132–133
GCO analyses, 133
headspace techniques, 133
olfactometry technique, 134
solid-phase micro extraction (SPME), 133
Volodkevich bite tenderometer (VBT), 20

W

Warmed-over flavor (WOF), 78–79
descriptors, 150
Warner–Bratzler shear (WBS), 122–124
correlation coefficients *(R),* 19–20
deformation and stress, 18
MIT Denture tenderometer, 20
operation, 17
standard protocol, 18–20
Volodkevich bite tenderometer (VBT), 20

Y

Yellowness index (YI), 333

© 2011 by Taylor and Francis Group, LLC