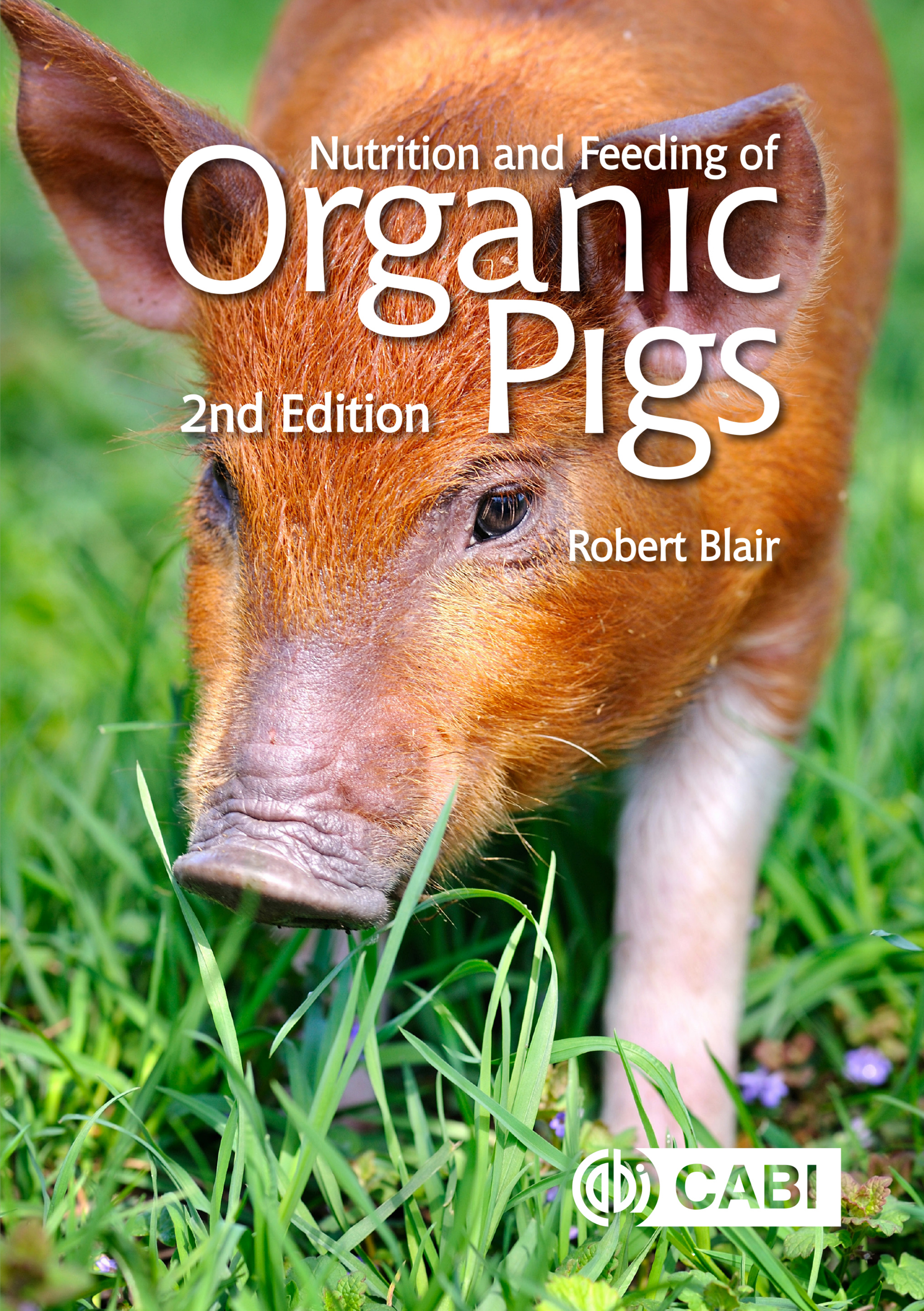

Nutrition and Feeding of

Organic Pigs

2nd Edition

Robert Blair

CABI

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Contents

1.	Introduction and Background	1
2.	Aims and Principles of Organic Pig Production	5
3.	Elements of Pig Nutrition	17
4.	Approved Ingredients for Organic Diets	44
5.	Diets for Organic Pig Production	170
6.	Choosing the Right Breed and Strain of Pig	205
7.	Integrating Feeding Programmes into Organic Production Systems	219
8.	Conclusions and Recommendations for the Future	250
Index		253

This book is enhanced with supplementary resources.
To access the computerized system of on-farm feed formulation please visit:
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1

Introduction and Background

In recent years there has been a rapid increase in organic animal production in many countries. This development is a response to an increased consumer demand for food that is perceived to be fresh, wholesome and flavoursome, free of hormones, antibiotics and harmful chemicals and produced in a way that is sustainable environmentally and without the use of gene-modified (GM) crops.

This publication sets out guidance on nutrition and feeding practices that relate to the standards for certification of organic pigs and the production of organic pork. Details on permitted feed ingredients, with an emphasis on those grown or available locally, and on suitable dietary formulations are included.

Organic farming can be defined as an approach to agriculture in which the aim is to create integrated, humane, environmentally and economically sustainable agricultural production systems. Thus maximum reliance is placed on locally or farm-derived renewable resources. In many European countries, organic agriculture is known as ecological agriculture, reflecting this emphasis on ecosystems management. The term for organic production and products differs within the European Union (EU). In English the term is ‘organic’; in Danish, Swedish and Spanish it is ‘ecological’; in German it is ‘ecological’ or ‘biological’; and in French, Italian, Dutch and Portuguese it is ‘biological’ (European Commission (1999): Regulation (EEC) No. 2092/91). In Australia the term used is ‘organic’, ‘bio-dynamic’ or ‘ecological’.

It is clear that the idealism set out initially in the principles of organic agriculture has had to be tempered by practical considerations. The standards adopted have to aim for a balance between the desire of consumers for organic products and considerations of ethical and ecological integrity, and the practical and financial needs of producers. As a result, synthetic vitamins are now allowed in organic pig feeds, with some restrictions.

An example whereby the regulations may have to be further modified is the situation regarding supplemental amino acids (AA). Some countries seek this change. At present pure AA are banned from organic diets in some countries on the grounds of being synthetic, or, if derived from microbial fermentation, are similarly banned because of the organisms used being GM. Lack of availability of pure AA for organic feed supplementation is known to result in diets of unbalanced protein composition, increased feed cost, inefficient protein utilization and a consequent increased nitrogen load on the environment. This effect is contrary to the aim of ecological integrity and is of considerable practical importance since organic agriculture relies exclusively on animal manure and other organic wastes as fertilizer.

The effect on the cost of meat to the consumer has also to be considered. This book will assist producers in formulating diets without supplemental AA and will examine the justification for their banning.

Another effect of the current regulations is that some organic feed mixtures in use do not meet the standards that some authorities seek to achieve. Several of the regulations are open to interpretation, derogations have had to be introduced in a number of countries to cope with shortages of organic feedstuffs, and synthetic vitamins have had to be allowed.

Forms of vitamins and minerals approved by the Food and Drug Administration (FDA) are allowed in organic diets in the USA even though they may not be considered natural substances or appear on the national list of Synthetic Substances Allowed for Use in Organic Production.

The standards and rules laid down to accomplish organic production place several restrictions on diets and feeding. These are detailed in the next chapter. A main aim of this book is to present advice on how the appropriate diets can be formulated and how feeding programmes can be integrated into an organic production system.

In general, the feed for use in organic pig production can contain ingredients from three categories only:

1. Agricultural products that have been produced and handled organically, preferably from the farm itself.
2. Non-synthetic substances such as enzymes, probiotics and others considered to be natural ingredients.
3. Synthetic substances that have been approved for use in organic pig production.

In addition, the diet is intended to ensure quality production of the animals rather than maximizing production, while meeting the nutritional requirements of the livestock at various stages of their development. The feeding of young mammals must be based on natural milk; consequently, the nursing period for pigs is set at a minimum of 6 weeks. Roughage, fresh or dried fodder, or silage must be added to the daily ration of pigs. In some jurisdictions this requirement is extended in order that the animals be allowed access to pasture. Generally the vitamins approved for dietary supplementation should be derived from feedstuffs or, if synthetic, identical to natural vitamins. However, natural sources such as sprouted grains and brewer's yeast may be preferred by some certifying agencies. A strict interpretation of the regulations to require synthetic vitamins to be identical in form to natural vitamins may appear to be logical, but from a practical standpoint poses problems in feed formulation. The natural forms of fat-soluble vitamins are unstable and lose potency very readily, and several of the natural forms of water-soluble vitamins are biologically unavailable to the animal. This issue will be discussed in more detail in a succeeding chapter.

Thus it would appear that at present the organic standards have been introduced before all of the scientific data required to make a successful change to sustainable and efficient organic production are available. Currently the relevant data have to be extrapolated from conventional pig production practices until all of the required data are available.

Jakobsen and Hermansen (2001) summarized the main problems and challenges posed by organic production on pigs in Denmark as follows:

> **1.** To establish the requirements and supply of energy, essential amino acids (EAA), vitamins and minerals under organic farming conditions, using the slow-growing breeds that are preferred over modern hybrids. The requirements for vitamins and minerals of pigs under organic farming conditions are not known.
> **2.** To develop feeding concepts in order to improve the resistance to infectious diseases of the gastrointestinal tract.
> **3.** To improve product quality and the economics of production. The quality of organically produced meat is of concern in Denmark, especially in relation to the fatness and the palatability of the meat.

A major challenge facing the organic pig industry is a shortage of organic feedstuffs, exacerbated by the objective in Europe of requiring the feed to be 100% organic by

31 December 2017 and a 110-fold increase in the global production of GM crops since 1996 (ISAAA, 2017). At present, most countries consider the feed to be organic with 5–10% of the ingredients being non-organic.

A large study has examined the feasibility of that objective (Smith *et al.*, 2014). It was funded through the European CORE Organic II ERA-net programme to support organic research, and led by Aarhus University in Denmark with 15 partners across 10 EU countries. It involved a range of feeding experiments with pigs (sows, piglets and finishers) and poultry (layers and broilers) that focused on concentrate feedstuffs, roughage, and foraging from pasture land. Based on the compiled data, the balance between feed supply and feed demand was calculated in terms of dry matter, energy, crude protein and essential amino acids: lysine, methionine and methionine + cystine. This analysis showed that for the countries involved in this project (ICOPP[1] countries) there was a self-sufficiency rate for organic/conventional feed of 69%. Over 50% of the total demand for concentrate feed was for bovine animals; 16% was for pigs and 31% for poultry. The self-sufficiency rate for crude protein was 56%. Except for Lithuania, the organic crude protein demand exceeded availability, with an overall gap of approximately 135,000 tonnes of crude protein existing within the ICOPP countries. The supply gap with essential amino acids was even higher than the supply gap with crude protein, being just above 50% for lysine and about 40% for methionine + cystine.

It was therefore concluded that:

> **1.** It seems quite unrealistic that the ICOPP countries will be able to cover the organic protein demand with their own efforts and increase production in the foreseeable future unless major shifts in production take place.
> **2.** A large of amount of concentrate feed is fed to ruminants. It would be beneficial if part of the concentrate feed for ruminants (total around 1,000,000 tonnes) could be used in feeding pigs and poultry.
> **3.** In order to meet the essential amino acid requirements for the individual animal categories, the types of protein crops that can be produced organically in a country is relevant. There are different feeding possibilities, which were researched in the ICOPP and other research projects, but still there is a need for more innovative solutions.
> **4.** Data on organic livestock and the market for livestock products are still scarce. There is a clear need for more and better data and for continuing and reliable data collection efforts in this field.
>
> (Smith *et al.*, 2014)

In attempting to reduce the supply gap in organic feedstuffs, the requirement for the inclusion of roughage, fresh or dried fodder or silage in the diet has to be addressed. To what extent are these ingredients utilized and how do they affect product quality? The high cost of organic grain and protein sources suggests that producers should explore the maximization of pasture contributions during months when grazing is practical. Should nutrient contributions from pasture be considered when formulating diets? These questions are difficult to answer, given the present state of knowledge. Some Danish research suggested that the vitamins and minerals present in the feed and soil, and synthesis from sunlight, can be utilized to a higher degree than normally believed. The issue of whether diets for pigs on pasture require supplementation with vitamins and minerals is addressed in a later chapter.

There is field evidence that some of the organic feed being used does not meet acceptable quality standards (Kienzle *et al.*, 1993; Thielen and Kienzle, 1994). It is to be hoped that this book will help to prevent that situation.

Although the main aim of this book is to provide information to assist advisory personnel, researchers, veterinarians, teachers and organic producers in formulating diets and feeding programmes for organic pigs, the regulatory authorities in several countries may find it of value in addressing nutritional issues relevant to future revisions of the regulations.

[1] Improved Contribution of local feed to support 100% Organic feed supply to Pigs and Poultry.

It seems clear that the current standards and regulations have been developed mainly by those experienced in crop production and in ecological issues, and that a review of the regulations from an animal nutrition perspective would be useful.

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2

Aims and Principles of Organic Pig Production

According to the Codex Alimentarius Commission and the Joint Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Food Standards Programme, organic agriculture is:

> [A] holistic production management system which promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity ... emphasizes the use of management practices in preference to the use of off-farm inputs as opposed to using synthetic materials. The primary goal is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people ... the systems are based on specific and precise standards of production which aim at achieving optimal agroecosystems which are socially, ecologically and economically sustainable.
> (Codex Alimentarius Commission, 1999)

Thus organic pig production differs from conventional production, and in many ways is close to the agriculture of Asia. It aims to fully integrate animal and crop production and develop a symbiotic relationship of recyclable and renewable resources within the farm system. Livestock production then becomes one component of a wider, more inclusive organic production system. Organic pig producers must take into consideration several factors other than the production of livestock. These factors include the use of organic feedstuffs (including limited use of feed additives); use of outdoor-based systems; restrictions on numbers of bought-in stock; group-housing of breeding stock; and minimizing environmental impact. Organic pig production also requires certification and verification of the production system. This requires that the organic producer must maintain records sufficient to preserve the identity of all organically managed animals, all inputs and of all edible and non-edible organic livestock products produced. The result is that organic food has a very strong brand image in the eye of the consumer and thus should command a higher price in the marketplace than conventionally produced food.

The whole organic process involves four stages: (i) application of organic principles (standards and regulations); (ii) adherence to local organic regulations; (iii) certification by local organic regulators; and (iv) verification by local certifying agencies.

Restrictions on the use of ingredients in organic diets include:

- No GM grain or grain by-products.
- No antibiotics, hormones or drugs. Enzymes are prohibited as feed ingredients used to increase feed conversion efficiency (they may be used under derogation where necessary for the health and welfare of the animal).

- No animal by-products, except that milk products are permitted.
- No grain by-products unless produced from certified organic crops.
- No chemically extracted feeds (such as solvent-extracted soybean meal).
- No pure AA, either synthetic or from fermentation sources (there are some exceptions to this provision).

Organic Standards

The standards of organic farming are based on the principles of enhancement and utilization of the natural biological cycles in soils, crops and livestock. According to these regulations organic livestock production must maintain or improve the natural resources of the farm system, including soil and water quality. Producers must keep livestock and manage animal waste in such a way that supports instinctive, natural living conditions of the animal, yet does not contribute to contamination of soil or water with excessive nutrients, heavy metals or pathogenic organisms, and optimizes nutrient recycling. Livestock living conditions must accommodate the health and natural behaviour of the animal, providing access to shade, shelter, exercise areas, fresh air and direct sunlight suitable to the animal's stage of production or environmental conditions, while complying with the other organic production regulations. The organic standards require that any livestock or edible livestock product to be sold as organic must be maintained under continuous organic management from birth to market. However, breeding stock may be brought in from a non-organic operation into an organic operation at any time provided that, if such livestock are gestating and the offspring are to be raised organically from birth, they are brought into the organic operation prior to the last third of pregnancy. Feed, including pasture and forage, must be produced organically and health care treatments must fall within the range of accepted organic practices. Organic livestock health and performance are optimized by careful attention to the basic principles of livestock husbandry, such as selection of appropriate breeds, appropriate management practices and nutrition, and avoidance of overstocking.

Young pigs should receive an adequate supply of colostrum at birth and should remain with their mothers for at least 40 days. Stress should be minimized at all times. Rather than being aimed at maximizing animal performance, dietary policy should be aimed at minimizing metabolic and physiological disorders; hence the requirement for some forage in their diet. Grazing management should be designed to minimize pasture contamination with parasite larvae. Housing conditions should be such that disease risk is minimized, i.e. ventilation should be adequate, stocking rate should not be excessive and adequate dry bedding should be available.

Nearly all synthetic animal drugs used to control parasites, prevent disease, promote growth or act as feed additives in amounts above those needed for adequate growth and health are prohibited in organic production. Dietary supplements containing animal by-products such as meat meal are also prohibited. No hormones can be used, a requirement which is easy to apply in pig production since hormone addition to feed has never been practised commercially. Veterinary use of hormone preparations has been used to treat agalactia in sows after birth and avoid mortality of piglets, and to induce parturition where advisable. Other measures can be used for these conditions. When preventive practices and approved veterinary biologics are inadequate to prevent sickness, the producer must administer conventional medications. However, livestock that are treated with prohibited materials must be clearly identified and cannot be sold as organic.

International Standards

The aim of organic standards is to ensure that animals produced and sold as organic are raised and marketed according to defined principles. International standards and state regulations in conjunction with accreditation and certification are therefore very important as guarantees for the consumer.

Currently there is no universal standard for organic food production worldwide. As a result many countries have now established national standards for the production and feeding of organic pigs. They have been derived from those developed originally in Europe by the Standards Committee of the International Federation of Organic Agriculture Movements (IFOAM) and the guidelines for organically produced food developed within the framework of the Codex Alimentarius, a programme created in 1963 by FAO and WHO to develop food standards, guidelines and codes of practice under the Joint FAO/WHO Food Standards Programme. IFOAM Basic Standards were adopted in 1998. Within the Codex, the Organic Guidelines include Organic Livestock production.

The IFOAM standard (IFOAM, 1998) is intended as a worldwide guideline for accredited certifiers to fulfil. IFOAM works closely with certifying bodies around the world to ensure that they operate to the same standards. The main purpose of the Codex (Codex Alimentarius Commission, 1999) is to protect the health of consumers and ensure fair trade practices in the food trade, and also promote coordination of all food standards work undertaken by international governmental and non-governmental organizations. The Codex is a worldwide guideline for states and other agencies to develop their own standards and regulations, but it does not certify products directly. Thus the standards set out in the Codex and by IFOAM are quite general, outlining principles and criteria that have to be fulfilled. They are less detailed than the regulations dealing specifically for regions such as Europe.

The sections of the Codex regulations relevant to the coverage of this book include the following:

1. Conventional pigs have to be reared under organic standards for 6 months before they are considered organic (i.e. the first litter after the conversion period can be sold as organic) (Annex 2.2.1).
2. Simultaneous conversion of land and livestock is possible as long as most of the feed for the animals comes from the converting farm (Annex 2.3.1).
3. The choice of breeds or strains should favour pigs that are well adapted to the local conditions and to the husbandry system intended. Vitality and disease resistance are particularly mentioned, and preference should be given to indigenous species (Annex 3.1).
4. An established breeding herd can bring in gilts from non-organic holdings to allow for natural growth in the herd to a maximum of 20% of the herd, if organically reared animals are not available (Annex 3.8). This number of bought-in breeding animals can be increased under special circumstances (major expansion, change of breed, new specialization developed) (Annex 3.10).
5. Boars can be brought in from non-organic holdings. But livestock brought in from non-organic holdings for breeding purposes cannot be sold as organic for either slaughter or breeding.
6. *Feeding*. Pigs must be fed to ensure quality rather than maximum growth rates (Annex 4.1). Pigs must be fed on organically produced feed (60% of home-grown feed can be in-conversion feed) (Annex 4.4). Roughage, fresh or dried fodder (grazing) or silage must be added to the daily ration. Certain feed materials of animal origin (milk or milk products and fish or fish by-products) and minerals and vitamins (including synthetic vitamins for pigs) can be used, as long as they are listed in Annex II 3.C. Antibiotics, coccidiostats, medicinal substances, growth promoters and any substances intended to stimulate growth or production must not be used in pig feed (Annex 4.17).
7. *Husbandry*. Piglets must be suckled for at least 40 days (Annex 4.5). Artificial insemination and castration are allowed (Annex 6.1.1 and 6.1.3).
8. *Housing and free-range conditions*. Pigs must have access to pasture or an open-air exercise area or an open-air run (Annex 8.3.1). The final finishing stage (maximum one-fifth of total lifetime) can take place indoors (Annex 8.3.4). Sows must be kept in groups, except in the last stages of gestation and during suckling. Exercise areas must permit dunging and rooting (soil is not necessary if other suitable material is provided).

Although there is no internationally accepted regulation on organic standards, the

World Trade Organization and the global trading community are increasingly relying on the Codex and the International Organization for Standardization (ISO) to provide the basis for international organic production standards, as well as certification and accreditation of production systems. Such harmonization will promote world trade in organic produce. The ISO, which was established in 1947, is a worldwide federation of national standards for nearly 130 countries. The most important guide for organic certification is ISO Guide 65:1996, General Requirements for Bodies Operating Product Certification Systems, which establishes basic operating principles for certification bodies.

Europe

Legislation to govern the production and marketing of food as organic within the EU was introduced for plant products in 1993 (Regulation (EEC) No. 2092/91). This Regulation defined organic farming, set out the minimum standards of production and defined how certification procedures must operate. Regulation (EEC) No. 2092/91 was supplemented by various amendments and in 2000 by further legislation (Council Regulation (EC) No. 1804/1999) covering livestock production. In addition to organic production and processing within the EU, the Regulation also covered certification of produce imported from outside the EU.

Regulation (EC) No. 1804/1999 (European Commission, 1999) allowed the range of products for livestock production to be extended and it harmonized the rules of production, labelling and inspection. It reiterated the principle that livestock must be fed on grass, fodder and feedstuffs produced in accordance with the rules of organic farming. The regulation set out a detailed listing of approved feedstuffs. However, it recognized that under the prevailing circumstances, organic producers might experience difficulty in obtaining sufficient quantities of feedstuffs for organically reared livestock. Accordingly it allowed for authorization to be granted provisionally for the use of limited quantities of non-organically produced feedstuffs where necessary. For pigs the regulations allowed for up to 15% of annual dry matter (DM) from conventional sources until 31 December 2007, 10% from 1 January 2008 until 31 December 2009, and 5% from 1 January 2010 until 31 December 2011. However, 100% organic diets for pigs (and poultry) will become compulsory in the EU from 1 January 2018, emphasizing the need for the development of sustainable feeding systems based entirely on organic feeds by that time.

In addition, an important provision of the EU Regulation was to permit the use of trace minerals and vitamins as feed additives to avoid deficiency situations. The approved products are of natural origin or synthetic in the same form as natural products. Other products listed in Annex II, Part D, sections 1.3 (enzymes), 1.4 (microorganisms) and 1.6 (binders, anti-caking agents and coagulants) were also approved for feed use. Roughage, fresh or dried fodder, or silage must be added to the daily ration but the proportion is unspecified. Consideration was given later to the possible approval of pure AA as approved supplements for organic feeds, at the instigation of several Member States. However approval was not given, on the grounds that the AA approved for commercial feed use were either synthetic or derived from fermentation processes involving GM organisms.

Under the EU regulations, each Member State is required to establish a National Competent Authority to ensure adherence to the law. Between the years 1992 and 1999 the various European governments took quite different approaches to how organic livestock production should be regulated and this difference persists to the present. In addition, within each European country the different certifying bodies also adopted different positions. The end result is a wide variety of standards on organic livestock across Europe. However, every certifying body in Europe must work to standards that at a minimum meet the EU organic legislation (a legal requirement).

This lack of harmonization is evident within Europe and within Member States.

According to the Danish regulations for organic farming, sows must have access to grass areas for a minimum of 150 days in the summer period (15 April–1 November). Piglets may not be weaned from the sow until they are 7 weeks old. Growing-finishing pigs of more than 8 weeks can be kept indoors provided they have free access to an open-air run and to roughage, fresh or dried fodder, or silage. The EU regulation (EC No. 1804/1999) includes cereal straw as a roughage, whereas this is not the case in the Danish amendment. Another example of the variation in standards can be observed in the UK. The designated National Competent Authority is the government Department for Environment, Food and Rural Affairs. It publishes its interpretation of EU organic legislation (DEFRA, 2004) in the form of the United Kingdom Register of Organic Food Standards (UKROFS). The main text in Section 1 of the document outlines the compulsory standards; Section 2 outlines information of an advisory nature which is not compulsory for licensed organic producers but is taken to represent good practice. All organic certifying bodies in the UK have to conform with the general UK standards set out in UKROFS. Private certifying bodies can set their own standards that have to be either equivalent to or stricter than the EU and UKROFS standards. In 2005 there were ten approved certification schemes for organic producers, the main certifying bodies being the Soil Association, the Organic Farmers and Growers and the Scottish Organic Producers Association. The standards of the Soil Association appear to be different to those of the other two and are reviewed frequently. Their standards have been approved by IFOAM. A UK producer therefore needs to check with the selected certifying body on specific issues before adopting organic production. Another check that may be appropriate is with supermarkets, if this method of marketing is to be used. Some supermarkets have adopted their own standards for organic produce. For instance, some strains of pig may appear to be ideal for outdoor production but produce meat which is too fatty for the retail market.

North America

USA

The National Organic Program (NOP) was introduced in the USA in 2002 (NOP, 2000). This is a federal law that requires all organic food products to meet the same standards and be certified under the same certification process. All organic producers and handlers must be certified by accredited organic certification agencies unless exempt or excluded from certification. A major difference between the US and European standards is that organic standards in the USA have been harmonized under the NOP. States, non-profit organizations, for-profit certification groups and others are prohibited from developing alternative organic standards. All organic food products must be certified to the National Organic Standards (NOS). Organic producers must be certified by NOP-accredited certification agencies. All organic producers and handlers must implement an Organic Production and Handling System Plan that describes the practices and procedures that the operation utilize to comply with the organic practice standards. Both state agencies and private organizations may be NOP-accredited. The NOS establishes the National List, which allows all non-synthetic (natural) materials unless specifically prohibited, and prohibits all synthetic materials unless specifically allowed. In other respects the standards for organic swine production are similar to European standards.

Canada

Canada issued a proposed official national standard for organic agriculture in 2006, which was updated in 2015 (CGSB 2015a). It is based on a draft of a Canadian Standard for Organic Agriculture which was developed by the Canadian General Standards Board in 1999, and then updated in 2015 (CGSB, 2015b) and recommendations from the Canada Organic Initiative Project (2011). The 1999 draft Standard provided basic guidelines for organic farming groups and certifying agencies across Canada to develop their own standards. These standards are based on the same set of principles as those in Europe and the USA. The Equivalency agreement includes guidelines for organic pork producers and provides the basis for certification.

The Canadian Food Inspection Agency (CFIA) began enforcing the standards in 2011. A Canadian Organic Office was established to allow the CFIA to provide an oversight to the process of certifying organic farms and products in Canada. The regulations also allowed for certified products to carry the official Canada Organic logo on their labels. The Quebec standard (CAAQ, 2016) contains some interesting specific requirements; for example, herd size is limited to 1500 feeder pigs per year – either 80 breeding sows (for farrow-to-finish operators) or 200 sows (for farrowing operators only) or their equivalents, when 100% of the feed is not produced on the site. In addition, the issue of latitude is addressed by permitting temporary confinement during periods of intemperate weather when the animals' health, security and well-being are threatened, or when necessary for the protection of crops, soil or water quality. In Eastern Canada, below the 50th parallel, prevailing conditions in the spring, summer and fall are considered appropriate for animals being outside. Exclusive winter production is prohibited. The animals must have access to a constant supply of good-quality fresh water. Bacteriological tests may be required, the parameters for analysis being total faecal and coliform content and atypical colonies. Readings for temperature, moisture and air quality must be made as required, and entered in records. Moisture and dust content should not prejudice the well-being of the herd, and for pigs the following concentrations not to be exceeded: ammonia 20 mg/kg; hydrogen sulphide 5 mg/kg; and carbon dioxide 50 mg/kg. No complete list of permitted feed ingredients is currently available. Pure amino acids obtained by natural processes are permitted in feed. This provision distinguishes between AA that are of synthetic origin (methionine) and those that are of fermentation origin (lysine, tryptophan and threonine).

Latin America and the Caribbean

IFOAM recently set up a regional initiative for Latin America and the Caribbean – El Grupo de America Latina y el Caribe (GALCI) – coordinated from an office in Argentina. Currently, GALCI represents 59 organizations from countries throughout Latin America and the Caribbean, including producers' associations, processors, traders and certification agencies. The purpose and objectives of GALCI include the development of organic agriculture throughout Latin America and the Caribbean.

Mexico

The Government of Mexico unveiled a new programme of rules and requirements for organic agriculture certification in 2013 (Oficial Diario de la Federación). The guidelines are similar to those in the USDA National Organic Program (NOP) and are equivalent to other internationally accepted guidelines, no doubt to facilitate trade in organic products. One interesting aspect of the Mexican regulations is that they place limits on the stocking rate on land, to ensure that the output of nitrogen in excreta from organic animals does not exceed 500 kg/ha/year (Mexican Organic Regulations (2013)).

Argentina

Argentina was the first country in the Americas to establish in 1992 standards for the certification of organic products equivalent to those of the EU and validated by IFOAM (GAIN, 2002). Argentinian organic products are admissible in the EU and the USA. Organic livestock and poultry production in Argentina is governed by the Servicio Nacional de Salud (SENASA), a government agency under the Ministry of Agriculture, through Resolution No. 1286/93 and also by the EU Resolution No. 45011. In 1999, the National Law on Organic Production (No. 25127) came into force with the approval of the Senate. This law prohibits marketing of organic products which have not been certified by a SENASA-approved certifying agency. Each organic certification agency must be registered with SENASA.

Brazil

In 1999, the Ministry of Agriculture, Livestock and Food Supply published the Normative Instruction No. 7 (NI7), establishing national standards for the production and handling of organically produced products, including a list of substances approved for and prohibited from use in organic production (GAIN, 2002). The NI7 defines organic standards for production, manufacturing, classification, distribution, packaging, labelling, importation, quality control and certification, of both animal- and plant-origin products. The policy also establishes rules for companies wishing to be accredited as certifying agencies, which enforce the NI7 and certify production and operations under the direction of the Orgao Colegiado Nacional (National Council for Organic Production). According to the GAIN (2002) report about half of the organic production in Brazil is exported, mainly to Europe, Japan and the USA, indicating that the Brazilian standards are compatible with those in the importing countries.

Chile

Chilean national standards came into effect in 1999 under the supervision of the Servicio Agrícola y Ganadero, which is the counterpart of the Plant Protection and Quarantine branch of the US Department of Agriculture. The standards are based on IFOAM standards.

Africa

Several countries in Africa have introduced organic regulations, to ensure the acceptability of products in export markets and to comply with local regulations. In general the regulations have been based on EU regulations relating to organic products.

IFOAM opened an Africa Organic Service Center in Dakar, Senegal, in 2005. A main aim of the centre is to bring together all the different aspects and key people involved in organic agriculture in Africa into a coherent and unified continent-wide movement. Another objective is the inclusion of organic agriculture in national agricultural and poverty reduction strategies.

A major area of organic production is East Africa, which currently leads the continent in production and exports of certified organic products. Cooperation between the Kenya Organic Agriculture Network (KOAN), the Tanzanian Organic Agriculture Movement (TOAM) and the National Organic Agricultural Movement of Uganda (NOGAMU) led to the development in 2007 of the East African organic products standard (EAS 456:2007).

South Africa and several other countries have introduced national standards for organic agriculture, based on IFOAM recommendations, EU regulations and Codex Alimentarius guidelines.

In keeping with the regulations developed for other countries, such as Mexico, which have climates that allow year-round access of livestock to range land, the organic regulations in Africa generally place limits on the amount of nitrogen that is allowed to be excreted onto the land (e.g. 170 kg N/ha/year).

Australasia

Australia

The Australian National Standard for Organic and Bio-Dynamic Produce (an agricultural system that introduces specific additional requirements to an organic system) was first implemented in 1992 as the Australian Export Standard for products labelled organic or bio-dynamic. It was later amended in 2005 (edition 3.1). The Standard is issued by the Organic Industry Export Consultative Committee of the Australian Quarantine and Inspection Service (AQIS, 2016). The Standard provides a nationally agreed framework for the organic industry covering production, processing, transportation, labelling and importation. Certifying organizations that have been accredited by the Australian competent authority apply the Standard as a minimum requirement to all products produced by operators certified under the inspection system. This Standard therefore forms the basis of equivalency agreements between approved certifying organizations and importing country requirements. Individual certifying organizations may stipulate additional requirements to those detailed in the Standard.

The Standard states that a developed organic or bio-dynamic farm must operate within a closed input system to the maximum extent possible. External farming inputs must be kept to a minimum and applied only on an 'as needs' basis. The Standard is therefore somewhat more restrictive in terms of the ability of the organic pig farmer in Australia to improve genotypes.

The Standard appears to be similar to European standards in relation to permitted feed ingredients, with feed supplements of agricultural origin having to be of certified organic or bio-dynamic origin. However, a derogation allows that, if this requirement cannot be met, the approved certifying organization may approve the use of a product that does not comply with the Standard provided that it is free from prohibited substances or contaminants, and it constitutes no more than 5% of the animals' diet on an annual basis. Permitted feed supplements of non-agricultural origin include minerals, trace elements, vitamins or provitamins only if from natural sources. Treatment of animals for trace mineral and vitamin deficiencies is subject to the same provision of natural origin. AA isolates (pure AA) are not permitted in organic diets.

Organic production in Australia has been protected by legislation since 1992, with amendments coming into force in 1998. Legislation covers crop production, animal husbandry, food processing, packaging, storage, transport and labelling. The legislation does not mandate that every farm labelling or selling organic produce must be certified; it is implemented only for the export of products derived from agriculture and labelled as organic.

These national standards are used to determine equivalency of imported and domestically produced organic products, and are those applied for accreditation. Certification bodies wishing to become accredited to these standards must apply to the Australian Quarantine and Inspection Service, the competent authority consenting to such accreditations. Seven Australian certification bodies had obtained government accreditation by the end of the year 2000. Of these seven certification bodies, five can export to the EU as provided for under Article 11 of Regulation (EEC) No. 2092/91; however, all seven can export to non-European countries such as Canada, Japan, Switzerland and the USA. Only one national certification body, the National Association for Sustainable Agriculture, is accredited by IFOAM. At present there are no foreign certification bodies working within Australia, and no local certification bodies work in association with international certification bodies.

New Zealand

Revised regulations on organic farming were issued by the New Zealand Food Safety Authority, Ministry of Agriculture and Forestry (NZFSA, 2011). The regulations had previously been issued in draft form in 2000 as an extract from the relevant EU regulation, and were subsequently amended to incorporate the US NOS requirements. The regulations set out the minimum requirements for organic production, and operators are allowed to adopt higher standards.

The regulations show similarities to European and North American standards; however, some aspects are included. In addressing the issue of climate, the regulations (akin to those in Quebec in the northern hemisphere) allow that the final finishing-pig production for meat may take place indoors, provided that this indoors period does not exceed one-fifth of the lifetime of the animal. Stocking rates are specified where the spreading of manure from housing onto pasture is undertaken. A detailed list of permitted feed ingredients is included in the regulations: minerals and trace elements used in animal feeding having to be of natural origin or, failing that, synthetic in the same form as natural products. Synthetic vitamins identical to natural vitamins are allowed. Roughage, fresh or dried, or silage must be added to the daily ration for pigs but the quantity is not specified.

Asia

China

The regulations governing organic animal and poultry production in China are set out in the AgriFood MRL Standard and are summarized below (Pixian Wang, personal communication). The Standard resembles in part the IFOAM standards but contains some unique features:

8.2 Introduction of Animals and Poultry
8.2.1 When organic animals cannot be introduced, conventional animals can be introduced provided they have been weaned and introduced within 6 weeks of birth.
8.2.2 The number of conventional animals introduced annually is no more than 10% of OFDC (Organic Foods and Development Certification Center) approved adult animals of the same kind. Under certain circumstances, the certifying committee will allow the number of conventional animals introduced annually to be more than 10% but not more than 40%. Introduced animals must go through the corresponding conversion period.
8.2.3 Male breeding animals can be introduced from any source, but can only be raised following approved organic procedures.
8.2.4 All introduced animals must not be contaminated by products of genetic-engineering products, including breeding products, pharmaceuticals, metabolism-regulating agents and biological agents, feeds or additives.
8.3 Feeds
8.3.1 Animals must be raised with organic feed and forage which has been approved by the national organic agency (OFDC) or by an OFDC-certified agency. Of the organic feed and forage, at least 50% must originate from the individual farm or an adjacent farm.
8.3.4 The certification committee allows the farm to purchase regular feed and forage during a shortage of organic feed. However, the regular feed and forage cannot exceed 15% for non-ruminants on a DM basis. Daily maximum intake of conventional feed intake cannot exceed 25% of the total daily feed intake on a DM basis. Exemptions due to severe weather and disasters are permitted. Detailed feed records must be kept and the conventional feed must be OFDC-approved.
8.3.6 The number of animals cannot exceed the stock capacity of the farm.
8.3.8 Newborn animals must receive colostrum. Pigs cannot be weaned earlier than 4 weeks.
8.4 Feed additives
8.4.1 Products listed in Appendix D are allowed to be used as additives.
8.4.2 Natural mineral or trace mineral ores such as magnesium oxide and green sand are allowed. When natural mineral or trace mineral sources cannot be provided, synthesized mineral products can be used if they are approved by OFDC.
8.4.3 Supplemental vitamins shall originate from geminated grains, fish liver oil, or brewing yeast. When natural vitamin sources cannot be provided, synthesized vitamin products can be used if they are approved by OFDC.
8.4.4 Chemicals approved by OFDC in Appendix D are allowed to be used as additives.
8.4.5 Prohibited ingredients include synthesized trace elements and pure AA.
8.5 Complete Feed
8.5.1.1 All the major ingredients in the complete feed must be approved by OFDC or an agency certified by OFDC. The ingredients plus additive minerals and vitamins cannot be less than 95% of the complete feed.
8.5.1.2 Additive minerals and vitamins can be derived from natural or synthesized products, but the complete feed cannot contain prohibited additives or preservatives.
8.5.2 The complete feed must meet the requirements of animals (or poultry) for nutrients and feeding goals. This can be confirmed by either of the following:

All chemical compositions meet the related national regulations or the related authority regulations.

Except for water, all other nutrients in the complete feed can meet the requirements of the animals during a different stage (i.e. growth, production or reproduction) if the complete feed is the sole nutrient source. This can be tested by the related national agency using approved procedures.

8.6 Feeding Conditions

8.6.1 The feeding environment (pen, stall) must meet the animal's physiological and behaviour requirements, in terms of space, shelter, bedding, fresh air and natural light.
8.6.2 Where necessary, artificial lighting can be provided to extend the lighting period but cannot exceed 16 hours per day.
8.6.3 All animals must be raised outdoors during at least part of the year.
8.6.4 It is prohibited to feed animals in such a way that they do not have access to soil, or that their natural behaviour or activity is limited or inhibited.
8.6.5 The animals cannot be fed individually, except adult males, sick animals or sows at late gestation stage.

India

The Government of India implemented a National Programme for Organic Production (NPOP) in 2001, the standards for production and accreditation being recognized by Europe and North America as compatible with their national standards. India is now an important exporter of organic oil seeds and cereal grains.

Japan

The established Japanese Agricultural Standards (JAS; MAFF, 2001) for organic agricultural production are based on the Codex guidelines for organic agriculture. The Ministry of Agriculture, Forestry and Fisheries issued JAS for organic animal products in 2005 that were updated in 2012 (MAFF, 2012). Since 2001 the JAS have required that organic products sold in Japan conform to the JAS organic labelling standard. The US NOP standards meet the JAS guidelines, allowing the importation of US organic products. Under revised regulations, organic certification bodies are required to be registered (accredited) with MAFF and are now called Registered Certification Organizations.

Republic of Korea

The Republic of Korea introduced an 'Act on the Management and Support for the Promotion of Eco-Friendly Agriculture/Fisheries and Organic Foods' in 2013, to be administered by the Ministry of Agriculture, Food and Rural Affairs (MAFRA). The regulations are compatible with those of the EU, the USA and Canada, allowing trade in organic products between Korea and these countries.

Russia

In 2014 the Russian State Duma approved and signed into effect the National Standard for Organic Products, to become effective in 2015 and be regulated by the Ministry of Agriculture. The Standard and Regulations are based on the EU Council Regulation (EC) No 834/2007 of 28 June 2007.

Other countries

In most developing countries, there are no markets for certified organic products. In some countries, however, organic urban markets are developing. Expanding demand for organic foods in developed countries is expected to benefit developing country exports by providing new market opportunities and price premiums, especially for tropical and out-of-season products. Developing country exporters, however, will need to meet the production and certification standards of developed countries and overcome consumer preferences for local production.

Impact

These international guidelines, regulations and standards have a strong impact on national standards. It seems clear that convergence or harmonization of these regulations will occur as the markets for organic feedstuffs and pork grow and countries seek to export to others.

A comparison of the above standards shows that many of the aims and requirements are similar. These requirements are likely to have the following impact on the pig producer, if the producer wishes to comply with the letter and spirit of the regulations:

- Organic feedstuffs have to be used. Restrictions include no GM grain or grain by-products; no grain by-products unless produced from certified organic crops; no antibiotics, hormones or drugs; no animal slaughter by-products; no chemically extracted feeds (such as solvent-extracted soybean meal); no pure AA. Deficiencies of limiting AA are likely to occur in organic pig diets in Europe due to difficulties in the supply of protein ingredients in sufficient quantity and the prohibition on feed-grade AA. These restrictions result in an increased cost of the feed and may have a detrimental effect on the environment in the form of excessive nitrogen loading from manure.
- Feedstuffs should be produced on the farm or at least in the region. This requirement has particular relevance to regions such as Northern Europe which does not have the climate that allows self-sufficiency in protein needs. A seasonal production pattern may be a necessary outcome of this requirement in some regions.
- The stock should be indigenous or acclimatized to the farm or region. Thus traditional, unimproved breeds are preferred over genetically improved hybrids, raising questions over the appropriate nutrient requirements of such stock.
- The breeding stock should be self-sustaining where possible. Limited numbers of bought-in stock are permitted and semen use is permitted, though generally natural mating is preferred. Thus genetic improvement can be expected to be slow, particularly where herds are expected to be closed.
- The size of the herd is generally limited by the amount of land for manure application.
- Weaning should last as long as possible and at least for 40 days. This has a beneficial influence on the piglets but places a greater strain on the sow, in terms of an extended period of milk production and possible loss of body condition. It can also result in impaired fertility and lower overall productivity. In addition it raises questions about the applicability of current feeding programmes for lactating sows in conventional production, where early weaning is practised routinely.
- Stock should produce well in outdoor conditions; therefore it has to be hardy and healthy. In addition, cold conditions can be expected to increase feed needs. Other related issues are that young pigs have to rely on iron from soil to meet their initial iron needs, thus pastures have to be managed and rotated to avoid the presence of parasites. Sows have to be managed in groups and thus during the dry period have to be fed in ways to avoid bullying and ensure the correct intake of feed individually.
- Health of the stock may be compromised because of the restrictions on treatments for disease outbreaks. Also a strict adherence to a policy of no synthetic feed supplements is likely to lead to instances of vitamin and trace mineral deficiencies. Reliance on forage and sunlight to provide all of the required vitamins and minerals is not supported by scientific evidence.

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3

Elements of Pig Nutrition

Like all other animals, pigs require five components in their diet as a source of nutrients: energy, protein, minerals, vitamins and water. A nutrient shortage or imbalance in relation to other nutrients will adversely affect their growth and ability to reproduce. Pigs need a well-balanced and easily digested diet for optimal reproduction and meat production. They are very sensitive to dietary quality because they grow quickly in relation to their body weight and make relatively little use of fibrous, bulky feeds such as lucerne hay or pasture because they are non-ruminants (have a simple stomach compartment). A diagram of the digestive system is shown in Fig. 3.1.

Digestion and Absorption of Nutrients

A summary outline of digestion and absorption in the pig follows. This provides a basic understanding of how the feed is digested and the nutrients absorbed.

Digestion is the preparation of feed for absorption, i.e. reduction of feed particles in size and solubility by mechanical and chemical means. Mechanical breakdown of feedstuffs is performed by chewing in the mouth and contractions of the muscles of the gastrointestinal walls. Chemical breakdown is achieved by enzymes secreted in digestive juices and by gut microflora. The digestive process reduces feed particles to a size and solubility that allows for absorption of digested nutrients through the gut wall into blood and lymph.

Mouth

Digestion begins in the mouth. Here feed is chewed into smaller pieces, which increases its surface area. This aids subsequent chemical reactions with various digestive juices and enzymes. Saliva produced in the mouth by the salivary glands moistens the dry feed so that it is easier to swallow. At this point the feed is tasted and, if accepted, swallowed. The saliva is slightly acidic. Pigs produce about 15 l of saliva daily. Pigs are the only farm animals whose saliva contains the enzyme ptyalin, which has some amylase activity to break down starch, but it is doubtful whether much starch is digested in the mouth since the feed passes quickly to the stomach by means of a series of muscular contractions (peristalsis) in the oesophagus.

Stomach

The stomach capacity of a 90-kg pig is 6–8 l. A churning action here further softens and

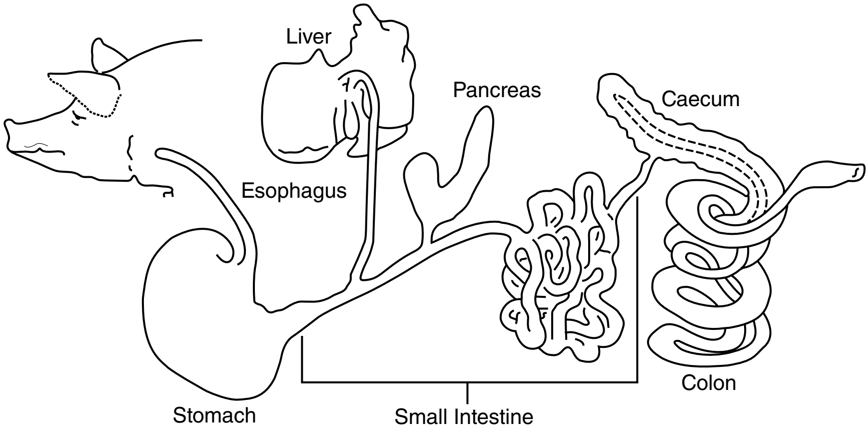

Fig. 3.1. Diagram of the digestive system of the pig.

separates feed particles, exposing them to gastric juices secreted by the stomach. These juices contain several enzymes, principally pepsin, which act to break down protein. Pepsin can function only in an acid medium (pH less than 3.5), acidity being provided by hydrochloric acid produced by the stomach. Hydrochloric acid dissolves minerals ingested with the feed such as calcium salts and inactivates pathogenic bacteria present in the feed. Mucus is also released by the stomach to protect the stomach wall from acid damage. The small amount of lipase present in gastric juices initiates the digestion of fat in the stomach. In nursing pigs, the gastric juices also include the enzyme rennin, which breaks down the protein in milk. Thorough mixing of the feed with acidic gastric juices takes place only in the lower region of the stomach. The contents of the upper stomach remain at an alkaline pH. This enables digestion of starch in the slightly alkaline medium of the stomach by salivary amylase. One or two hours after eating, partially digested feed in a semi-fluid form known as chyme moves from the stomach into the small intestine.

Small intestine

The small intestine is a long tube-like structure connecting the stomach to the large intestine. This is where digestion is completed and absorption of nutrients takes place. Its capacity in the pig is about 9–10 l. Absorption includes various processes that allow the end-products of digestion to pass through the membranes of the intestine into the bloodstream for distribution throughout the body. Some absorption also takes place in the stomach.

Chyme is mixed with other fluids in the small intestine, the first part of which is known as the duodenum. Duodenal glands produce an alkaline secretion which acts as a lubricant and also protects the duodenal wall against hydrochloric acid entering from the stomach. The pancreas (which is attached to the small intestine) secretes fluid containing bicarbonate and several enzymes (amylase, trypsin, chymotrypsin and lipase) that act on carbohydrates, proteins and fats. The duodenal wall also secretes enzymes which continue the breakdown process on sugars, protein fragments and fat particles. Bile synthesized by the liver passes into the duodenum via the bile duct. It contains bile salts which provide an alkaline pH in the small intestine and fulfil an important function in digesting and absorbing fats.

As a result of these activities the ingested carbohydrates, protein and fats are broken down into small molecules. Muscles in the wall of the intestine regularly contract and relax, mixing the chyme and moving it towards the large intestine.

Newborn pigs, for a short time after birth, possess the ability to absorb large molecules in a manner similar to that by which an amoeba surrounds its food source (pinocytosis). This is important in that it allows newborn pigs to receive immunoglobulin from colostrum, which provides some immunity against diseases in the environment. Another feature of the young pig is its great ability to digest fat from sow's milk, which is high in this component.

Jejunum and ileum

Absorption also takes place in the second section of the small intestine, known as the jejunum, and in the third section, known as the ileum.

Digestion and absorption are complete by the time the ingesta have reached the terminal end of the ileum. This area is therefore of interest to researchers studying nutrient bioavailability (relative absorption of a nutrient from the diet) since a comparison of dietary and ileal concentrations of a nutrient provides information on its removal from the gut during digestion and absorption.

Minerals and vitamins are not changed by enzymatic action. They dissolve in various digestive fluids and water, and are then absorbed.

Once the nutrients enter the bloodstream, they are transported to various parts of the body for vital body functions. Nutrients are used to maintain essential functions such as breathing, circulation of blood and muscle movement, replacement of worn-out cells (maintenance), growth, reproduction and secretion of milk (production).

The remaining ingesta, consisting of undigested feed components, intestinal fluids and cellular material from the abraded wall of the intestine, then passes to the next section of the intestine, the large intestine.

Large intestine

The large intestine (lower gut) consists of two parts: a sac-like structure called the caecum and the last section, called the colon. The colon is attached to the rectum. The caecum is small, with a capacity of about 1.5–2 l. Here the intestinal contents move slowly and no enzymes are added. Some microbial breakdown of fibre and undigested material occurs, but absorption is limited. Thus fibrous feeds, such as lucerne, have limited feed value. Remaining nutrients, dissolved in water, are absorbed in the lower part of the colon (about 9 l capacity). The nutritional significance of certain water-soluble vitamins and proteins synthesized in the large intestine is doubtful because of limited absorption in this part of the gut.

The large intestine absorbs much of the water from the intestinal contents into the body, leaving the undigested material which is formed into the faeces and later expelled through the anus.

The entire process of digestion requires about 24–36 h.

Digestibility

Only a fraction of each nutrient taken into the digestive system is absorbed. This fraction can be measured as the digestibility coefficient. It is determined through animal digestibility experiments. Researchers measure both the amount of nutrient present in the feed and the amount of nutrient present in the faeces, or more exactly in the ileum. The difference between the two, commonly expressed as a percentage or in relation to 1 (1 indicating complete digestion), is the amount of the nutrient digested by the pig. Each feedstuff has its own unique set of digestibility coefficients for all nutrients present. The digestibility of a feedstuff or a complete feed can also be measured. Digestibility measured in this way is known as apparent digestibility since the faeces and ileal digesta contain substances originating in the fluids and mucin secreted by the gut and associated organs, as well as cellular material abraded from the gut wall as the digesta pass. Correction for these endogenous losses allows true digestibility to be measured. Generally, the digestibility values listed in feed tables refer to apparent digestibility unless stated otherwise.

Some feed ingredients contain components that interfere with digestion. This aspect is dealt with in Chapter 4.

Nutrient Requirements

Energy

Energy is produced when the feed is digested in the gut. The energy is then either released as heat or is trapped chemically and absorbed into the body for metabolic purposes (Fig. 3.2). It can be derived from protein, fat or carbohydrate in the diet. In general, cereal grains and fats provide most of the energy in the diet. Energy in excess of requirement is converted to fat and stored in the body. The provision of energy accounts for the greatest percentage of feed costs.

The total energy (gross energy; GE) of a feedstuff can be measured in a laboratory by burning it under controlled conditions and measuring the energy produced in the form of heat. Digestion is never complete under practical situations; therefore measurement of GE does not provide accurate information on the amount of energy useful to the animal. A more precise measurement of energy is digestible energy (DE), which takes into account the energy lost during incomplete digestion and excreted in the faeces. Much research has been conducted on this topic and there is now a large database of DE values for feedstuffs, which is used widely by nutritionists in formulating pig diets.

The chemical components of feedstuffs have a large influence on DE values, with increased fat giving higher values and increased fibre and ash giving lower values. Fat provides about 2.25 times the energy provided by carbohydrates or protein. These relationships have been quantified by researchers to allow DE values to be predicted from chemical composition when no determined DE values are available.

More accurate measures of useful energy contained in feedstuffs are metabolizable energy (ME; which takes into account energy loss in the urine) and net energy (NE; which in addition takes into account the energy lost as heat produced during digestion). These measures are more difficult to obtain and in the case of ME may be calculated from DE rather than measured directly. As a result, DE is the most common energy measure used in pig nutrition, at least in North America.

The ME system is widely used in Europe and to some extent in North America. Where ME is used it is often calculated from DE, using a factor of 0.96 (ME = DE × 0.96). Feed composition tables may quote ME values, but many of these have been calculated from DE using this or a similar formula.

The DE of a feedstuff is not constant for all classes of pig since older animals and sows fed on restricted-feed intakes are better able to digest the feed. Therefore some

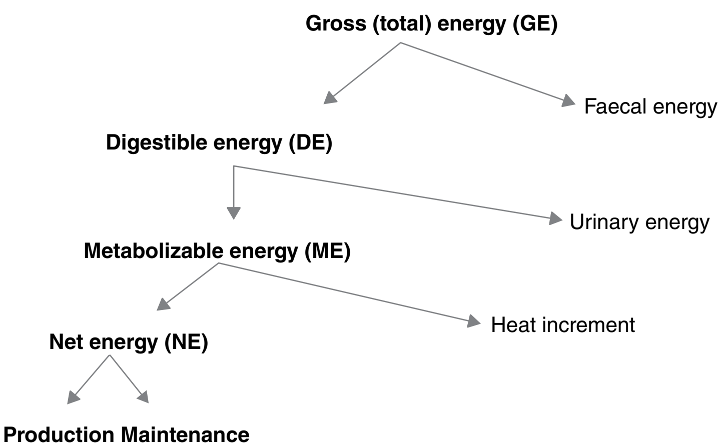

Fig. 3.2. Schematic of energy utilization in the pig showing how the various measures of feed energy are derived.

nutritionists adjust the DE value according to age of the animals being fed.

The requirements set out in this publication and taken mainly from the report *Nutrient Requirements of Swine* (NRC, 1998) were derived from pigs raised conventionally, not organically. They are based on DE, expressed as kilocalories (kcal) or megacalories (Mcal) per kg feed. This energy system is used widely in North America and in many other countries. Energy units used in some countries are based on joules (J), either kilojoules (kJ) or megajoules (MJ). A conversion factor can be used to convert calories to joules, i.e. 1 Mcal = 4.184 MJ, 1 MJ = 0.239 Mcal and 1 MJ = 239 kcal. Therefore the tables of feedstuff composition in this publication show DE and ME values expressed as MJ or kJ as well as kcal per kg.

Some countries in Europe, such as Denmark and The Netherlands (CVB, 2000), use feeding systems based on NE. These systems are more precise than systems based on DE or ME but they need the requirements to be based on NE also, the data for which are not yet widely available.

Net energy (NE) is defined as ME minus the heat increment, which is the heat produced during digestion of feed, metabolism of nutrients and excretion of waste. The energy remaining after these losses have been deducted is the energy actually used for maintenance and for production (growth, gestation, lactation). This means that the NE system is the only one that describes the energy that is actually used by the pig. NE is, therefore, the most accurate and unbiased way to date of characterizing the energy content of feeds. However, NE is much more difficult to determine and more complex than DE or ME, which may be a reason why it is not as widely used as it should be. Currently, France, The Netherlands, Denmark, the UK and Germany have developed NE systems to describe dietary NE contents, although research into NE has been conducted in several countries.

A limitation of the NE system is that it is not possible to determine the NE content of feed ingredients directly. Generally the French method developed by Noblet *et al.* (1994) has been used to estimate the NE content of feed ingredients from DE content and analysed nutrient contents, i.e.:

NE = (0.700 × DE) + (1.61 × EE) + (0.48 × Starch) – (0.91 × CP) – (0.87 × ADF), where EE is ether extract (crude fat), CP is crude protein and ADF is acid detergent fibre, the EE, CP and ADF contents being in g/kg and the NE and DE contents being in kcal/kg.

Digestible energy requirements are applied most precisely in the case of animals which are fed rationed amounts of feed, e.g. gestating sows. The DE requirement of the gestating sow varies with body weight, weight gain, environmental temperature and other factors. Assuming that the sow gains 25 kg in body weight during pregnancy and gains 20 kg in the form of piglets plus uterine and udder tissue, the maintenance need can be calculated as being similar to that of a growing-finishing pig and the need for gain can be calculated as 1.29 Mcal DE/kg. Thus the total requirement is 5.8–6.8 Mcal DE/day for a 120–160 kg animal at the start of pregnancy, equivalent to 1.8–2.0 kg daily of a maize/soy diet.

The powerful anabolic effect of pregnancy can be seen in Table 3.1 (from Friend *et al.*, 1982).

In Table 3.1 all animals received the same total amount of feed, yet the bred animals were able to produce a litter of pigs while achieving the same live weight after farrowing as the unbred animals. These data demonstrate, in a rather spectacular way, the increased efficiency of the pregnant animal and explain why gestating pigs need to be fed restricted amounts of feed to prevent them becoming too fat. This increased efficiency can be explained by the effect of

Table 3.1. Growth and farrowing data for gilts bred or not bred at puberty and given restricted amounts of feed (from Friend *et al.*, 1982).

	Bred	Unbred
Age at breeding (days)	163	166
Weight at breeding (kg)	98	98
Weight at 85 days (kg)	116	108
Weight at 100 days (kg)	122	113
Weight after farrowing (kg)	115	118
Piglets born (*n*)	9.1	–
Piglets born alive (*n*)	8.5	–

hormonal changes during pregnancy on metabolism.

For the lactation stage a milk yield of 5–7.5 kg/day can be assumed, also that the maintenance need is the same as for as for the pregnant sow. Thus the total need is 14.5–20.5 Mcal DE/day for sows of 145–185 kg post-farrowing, equivalent to 4.4–6.1 kg daily of a maize/soy diet.

In the case of other classes of pigs which are fed *ad libitum* (feeding to appetite), the DE requirements are met by regulating the DE content of the dietary mixture.

The main sources of energy are starch and fat. Very young weaned pigs need some simple sugars. Fibre is not well utilized and increased fibre in the diet may result in reduced digestibility of energy and protein. Although fibre cannot be digested in pigs it may be broken down to some extent by microbial action in the lower gut, providing 5–28% of the DE requirement for maintenance in the form of volatile fatty acids. In addition to providing energy, fats supply some essential fatty acids (EFA). According to the NRC (1998), linoleic acid is the only required EFA.

The requirement tables published in the NRC (1998) report assume *ad libitum* feeding in most cases. Where limit (restricted) feeding is used the requirements are set out as total amounts of nutrients to be consumed daily. Because of the need in most instances to try and obtain maximum intake of feed and in other instances to find ways of controlling feed intake, research has been conducted on the factors that control voluntary feed intake. Among the factors known to be important is diet composition. For instance, pigs will eat more of a low-protein diet than of an unbalanced protein diet; fat inclusion in the diet delays stomach emptying; intake is related inversely to energy concentration in the diet; a high environmental temperature reduces appetite; and a low environmental temperature increases intake but the higher intake may be used mainly to maintain body temperature and not enhance growth. Also, it is known that castrates eat more than boars or gilts and that some breeds such as Durocs and crossbreeds eat more.

In the case of piglets and growing pigs the digestibility and palatability of the diet, as well as the balance of dietary amino acids (AA), have to be considered in ensuring a desirable feed intake. With finishing pigs nearing market weight it may be necessary with some breeds to reduce the energy level of the diet to ensure good carcass grades.

Bulky feeds are sometimes used with gestating sows to prevent them becoming too fat. With lactating sows a high-energy feed may assist in maintaining adequate milk production when the appetite is low. Also the correct calcium and phosphorus contents of the diet have to be used, otherwise intake can suffer. It is also known that too much feed in pregnancy leads to reduced intake during lactation.

Protein

The term protein usually refers to crude protein (CP; measured as nitrogen content × 6.25) in feedstuffs composition and requirement tables.

Protein is required in the diet as a source of AA, which can be regarded as the building blocks for the formation of muscle tissue, milk, etc. There are 22 different AA in the pig's body, ten of which are essential (EAA; arginine (conditionally), methionine, histidine, phenylalanine, isoleucine, threonine, leucine, tryptophan, lysine and valine), i.e. cannot be manufactured by the body and must be derived from the diet. Cystine and tyrosine can be regarded as semi-essential in that they can supply part of the sulphur-containing and aromatic AA requirements, respectively. The other ten are non-essential (NEAA) and can be made by the body.

The most important EAA in pig feeding is lysine, which is usually the first-limiting AA and has to be at the correct level in the diet. The level of the first-limiting AA in the diet normally determines the use that can be made of the other EAA. If the limiting AA is present at only 50% of requirement, then the efficiency of use of the other AA will be limited to 50%. This concept explains why a deficiency of an individual AA is not accompanied by specific deficiency signs: a deficiency of any EAA results in a generalized protein deficiency. The primary sign is usually a reduction in feed intake that is accompanied by increased feed wastage, impaired growth and general unthriftiness. Excess AA are not stored in the body but are excreted in the urine as nitrogenous compounds, some of which are converted to ammonia by microorganisms in the faeces.

In most pig diets, a portion of each AA present is not biologically available to the animal. This is because most proteins are not fully digested and the AAs are not fully absorbed. The AAs in some proteins, such as milk products, are almost fully bioavailable, whereas those in other proteins such as certain plant seeds are less bioavailable. It is therefore more accurate to express AA requirements in terms of bioavailable AA. Bioavailability is measured as the proportion of dietary EAAs that has disappeared from the gut when digesta reach the ileum. The NRC recommends formulation on the basis of bioavailable EAAs when the ileal digestibility of lysine, methionine, threonine or tryptophan is less than 70% or more than 90%.

For optimal performance the diet must provide adequate amounts of EAAs, adequate energy and adequate amounts of other essential nutrients. All of these must be of high bioavailability. Some variation in total dietary protein level can be tolerated, provided the correct levels of AAs are maintained. Gilts and boars, which are leaner and eat less, need higher levels of EAAs and CP in the diet than castrates which are fatter and eat more. Maximal carcass leanness requires a greater intake of EAAs than does maximal growth rate.

The CP requirement values outlined by the NRC (1998) assume a maize/soy diet and have been adjusted for the average bioavailabilities of EAA in maize/soy diets. A separate table on bioavailabilities is now included in the NRC publication, allowing the dietary target values to be adjusted when diets based on other feedstuffs are formulated.

The bioavailability of AAs in a wide range of feedstuffs has been measured by researchers. The primary method has been to measure the proportion of a dietary AA that has disappeared from the gut when digesta reach the terminal ileum, using surgically altered pigs. Interpretation of the data is, however, somewhat complicated. The values determined by this method are more correctly termed 'ileal digestibilities' rather than bioavailabilities because AAs are sometimes absorbed in a form that cannot be fully used in metabolism. Furthermore, unless a correction is made for endogenous AA losses, the values are 'apparent' rather than 'true'. Minimum endogenous losses are accounted for in the NRC (1998) estimates of requirements; thus both requirements and ingredient contents are expressed in terms of 'true' (or standardized) ileal digestible AA.

The estimates of requirement are based on the assumption that the pattern of dietary bioavailable EAAs should remain relatively constant during all growth stages. This pattern has been called ideal protein.

The CP need is minimized as the dietary EAA pattern approaches that of ideal protein. The nearer the EAA composition of the diet is to ideal protein, the more efficiently the diet is utilized and the lower the level of nitrogen excretion. Energy is also used most efficiently at this point; thus both protein and energy utilization are maximized.

The ideal proportions of AAs, based on digestible AAs and lysine as the first-limiting AA, are shown in Table 3.2.

Cereal grains, such as maize, barley, wheat and sorghum, are the main ingredients of pig diets and usually provide 30–60% of the total AA requirements. Other sources of protein such as soybean meal and canola meal must be provided to ensure adequate amounts and a proper balance of EAAs. The protein levels necessary to provide adequate intakes of EAAs will depend on the feedstuffs used. Feedstuffs that contain 'high-quality' proteins (i.e. with an AA pattern similar to the pig's needs) or mixtures of feedstuffs in which the AA pattern of one complements the pattern in another will meet the EAA requirements at lower dietary protein levels better than feedstuffs with a less desirable AA pattern. This is important if one of the goals is to minimize nitrogen excretion.

Table 3.2. Ideal dietary amino acid pattern for pigs, relative to lysine at 100 (true digestible basis) (from Baker, 1996; Close and Cole, 2000).

	Growing-finishing pigs (weight kg)				
Amino acid	5–20	20–50	50–100	Lactating sows	Pregnant sows
Lysine	100	100	100	100	100
Isoleucine	60	60	60	60	70
Leucine	100	100	100	112	100
Methionine	30	30	30	30	30
Methionine + cystine	60	65	70	50	55
Phenylalanine + tyrosine	95	95	95	110	100
Threonine	65	67	70	60	70
Tryptophan	18	19	20	18	20
Valine	68	68	68	70	78
Histidine	32	32	32	35	33

The profile of AAs in a feedstuff is a main determinant of its value as a protein source. If the profile indicates a relatively high content of lysine and is close to that of ideal protein (as in milk or fishmeal), it is considered a high-quality protein. Correct formulation of the diet ensures that the dietary AAs (preferably on a bioavailable basis) are as close to ideal protein as possible and with minimal excesses of EAAs.

The AA requirements of growing-finishing pigs, expressed in terms of dietary concentration, increase as the energy density of the diet increases. The data of Chiba *et al.* (1991a,b) indicate that, at higher or lower energy densities than those found in standard grain/soybean meal diets, the AA requirements (expressed as a percentage of the diet) may need to be adjusted upwards or downwards, respectively. Formulation should also ensure that the diet contains the correct amount of energy in relation to EAAs to promote lean tissue growth. Too much energy in relation to lysine will lead to a fat carcass. Too little energy in relation to lysine will result in reduced muscle growth and protein wastage. Some nutritionists formulate pig diets using the ratio of DE to lysine to optimize pig performance. This ratio has not yet been well developed for general usage since the optimal DE:lysine ratio is not an absolute value but is affected by factors such as genotype, sex, health status and environmental conditions.

Estimated AA requirements are shown in the tables at the end of this chapter, based on the concept of ideal protein (NRC, 1998).

Minerals

Under natural conditions it is likely that pigs can obtain part of their mineral requirements by eating pasture and rooting in the soil. However, these sources cannot be guaranteed to provide all of the requirements consistently. Therefore pig diets must be supplemented with sources of minerals.

Minerals required in large amounts are known as macro minerals. These include calcium, phosphorus, sulphur, sodium, chloride, potassium and magnesium. Minerals required in small amounts are called micro or trace minerals. These include iron, zinc, copper, manganese, iodine and selenium.

Minerals perform important functions in the animal body and are essential for proper growth, reproduction and lactation. In addition to being constituents of bone and teeth they take part in other essential processes. A lack of minerals in the diet can result in deficiency signs, including reduced or low feed intake, reduced rate of growth, soft or brittle bones, beading of the ribs, stiffness or malformed joints, posterior paralysis, goitre, unthriftiness, hairless piglets, breeding and reproductive problems, poor milk production and death.

Pigs need at least 14 mineral elements and it is possible that other minerals may also be essential in the body. Of the essential mineral elements, ten are likely to be deficient in pig diets. These are calcium, phosphorus, sodium, chloride, cobalt, iron, copper, zinc, iodine and selenium, but cobalt is not needed if the diet contains sufficient vitamin B_{12}. Deficiencies of the other four essential mineral elements are not common and the feeds used probably provide them in sufficient quantities. There are some indications that magnesium supplementation may be beneficial under certain situations.

Required minerals can be categorized as shown in Table 3.3.

Calcium and phosphorus

Calcium and phosphorus make up over 70% of the mineral content of the pig body, mainly combined with each other. Approximately 80% of the phosphorus and 99% of the calcium in the body are present in the bones and teeth. These figures indicate the importance of calcium and phosphorus in the diet and the role they play in giving rigidity and strength to the skeletal structure. An inadequate supply of either one in the diet will limit the utilization of the other. These two minerals are discussed together because there is a close relationship between them.

A deficiency of calcium is more likely than a deficiency of phosphorus. Cereal grains, which constitute most of the pig diet, are quite low in calcium. The phosphorus content of cereal grains is higher, although about one-half or more is in the form of phytin which is relatively unavailable to the pig. As a result the requirements are now set out in terms of available phosphorus. Generally the calcium present in cereal grains and most feedstuffs is of higher availability than that of phosphorus. Legumes and pasture provide some calcium.

Table 3.3. Minerals required by pigs.

Macro minerals	Trace minerals
Calcium (Ca)[a]	Cobalt
Chloride (Cl)[a,c]	Copper (Cu)[b]
Magnesium (Mg)	Iodine (I)[c]
Phosphorus (P)[a]	Iron (Fe)[b]
Potassium (K)	Manganese (Mn)[b]
Sodium (Na)[a]	Selenium (Se)[b]
Sulphur (S)	Zinc (Zn)[b]

[a]Included as dietary ingredients.
[b]Included in a premix.
[c]Normally included as iodized salt (NaCl).

Dietary calcium and phosphorus requirements are considered to be higher for maximum bone development than for gain and feed efficiency. Higher dietary mineral levels should also be considered for pregnant sows which are on a restricted daily feed intake of 1.8 kg. Calcium and phosphorus requirements of sows are higher with longer lactation periods and as the number of litters increases.

Adequate calcium and phosphorus nutrition for all classes of pigs is dependent upon: (i) an adequate supply of each mineral in an available form in the diet; (ii) a suitable ratio of available calcium and phosphorus in the diet; and (iii) the presence of adequate vitamin D (NRC, 1998). A wide calcium:phosphorus ratio lowers phosphorus absorption, resulting in reduced growth and bone calcification, especially if the diet is marginal in phosphorus. The ratio is less critical if the diet contains excess phosphorus. A suggested ratio of total calcium to total phosphorus for grain/soybean meal diets is between 1:1 and 1.25:1. When based on available phosphorus, the ratio is between 2:1 and 3:1. An adequate amount of vitamin D is also necessary for proper metabolism of calcium and phosphorus, but a very high level of vitamin D can mobilize excessive amounts of calcium and phosphorus from bones. The dietary calcium and phosphorus requirements, expressed as a concentration in the diet, may be slightly higher for gilts than for castrates. The calcium and phosphorus requirements of the developing boar are greater than those of the castrate and gilt (NRC, 1998). The calcium and phosphorus requirements of sows and gilts are influenced by how long the sow suckles the piglets, a factor of importance to organic producers. Weaning the litter at 5–8 weeks of age results in a greater drain on the sow than weaning at 3–4 weeks. Larger and heavier litters also place more stress on calcium and phosphorus needs.

During pregnancy the requirements for calcium and phosphorus increase in proportion to the need for fetal growth, and reach a maximum in late gestation. Generally, the requirements for calcium and phosphorus are based on a feeding level of 1.8–2.0 kg feed/day during gestation and 5–6 kg feed/day during lactation. If sows are fed less than 1.8 kg feed/day during gestation, the diet should be formulated to ensure sufficient concentrations of calcium and phosphorus to meet the daily requirements. The voluntary feed intake of lactating sows may be reduced by high environmental temperature. In this event the lactation diet should be formulated to meet the daily needs for calcium and phosphorus at the lower feed intake. Adequate calcium and phosphorus intakes are more critical in first-parity sows than in mature sows.

A high proportion of the phosphorus in cereal grains, grain by-products and oilseed meals is bound in the form of phytate, which is poorly available to the pig (NRC, 1998). The biological availability of phosphorus in cereal grains is variable, ranging from less than 15% in maize to approximately 50% in wheat. The greater availability of phosphorus in wheat and wheat by-products is due to the presence of a phytase enzyme in the grain, which releases phosphorus during digestion. The phosphorus in oilseed meals also has low bioavailability. In contrast, the phosphorus in protein sources of animal origin is largely inorganic (meaning in this context not containing carbon; organic compounds are those containing carbon), and most animal protein sources (including milk and blood by-products) have high phosphorus bioavailability (Cromwell, 1992). The phosphorus in dehydrated lucerne meal is highly available. Steam pelleting has been shown to improve the bioavailability of phytate phosphorus in some studies but not in others. The phosphorus in inorganic phosphorus supplements also varies in bioavailability. The phosphorus in defluorinated rock phosphate is generally less available than in monocalcium phosphate or monosodium phosphate, but can vary depending on source and processing.

Less is known about the availability of calcium in feedstuffs, but the level of calcium is generally so low that the bioavailability is of little consequence. The calcium in limestone, gypsum and oystershell flour is highly available, but the calcium in dolomitic limestone is only 50–75% available. Particle size (up to 0.5 mm in diameter) appears to have little effect on calcium availability. Pig data are not available, but on the basis of poultry data the calcium in dicalcium phosphate, tricalcium phosphate, defluorinated phosphate, calcium gluconate, calcium sulphate and bone meal is highly available (Baker, 2001).

Signs of calcium or phosphorus deficiency are similar to those of vitamin D deficiency (NRC, 1998). They include depressed growth and poor bone mineralization, resulting in rickets in young pigs and osteomalacia in older pigs. Calcium is removed from the bones to meet the demands of milk production when the sow diet contains insufficient calcium. Symptoms include lameness and stiffness in the hindquarters, with possible fractures of the pelvic and leg bones (posterior paralysis). The problem occurs most frequently in sows producing high levels of milk towards the end or just after the end of lactation. Excess levels of calcium and phosphorus can reduce the growth rate of pigs and the effect is greater when the calcium:phosphorus ratio is increased. Excess calcium not only decreases the utilization of phosphorus but also increases the requirement for zinc in the presence of phytate and may result in zinc deficiency. Excess calcium also increases the requirement for vitamin K.

Sodium, potassium and chloride

Sodium, potassium and chloride are the primary dietary ions that influence the electrolytic balance and acid–base status. Chloride is present in gastric juices and chlorine is part of the hydrochloric acid molecule which assists in the breakdown of feed in the stomach. Sodium is essential for nerve membrane stimulation and ionic transport across cell membranes. A dietary level of 0.20–0.5% added sodium chloride should generally meet the dietary sodium and chlorine requirements of growing-finishing and breeding pigs. The sodium and chloride requirements of breeding animals are not well established. In a regional study, piglet birth weights and weaning weights were reduced when sodium chloride addition was reduced from 0.50 to 0.25% during gestation and lactation for two or more parities (Cromwell *et al.*, 1989). Based upon the sodium contained in sow's milk (0.03–0.04%; ARC, 1981), the dietary sodium requirement should be about 0.05 percentage units greater during lactation than during gestation.

A deficiency of salt can result in loss of appetite and a reduction in the rate and efficiency of growth. In contrast, pigs can tolerate high dietary levels of sodium chloride (NRC, 1980) provided they have access to ample non-saline drinking water. If non-saline water is limited or if the level of sodium chloride in water is high, toxicity can result. The high sodium ion concentration is responsible for adverse physiological reactions, apparently because of a disturbance in water balance. The signs of sodium toxicity include nervousness, weakness, staggering, epileptic seizures, paralysis and death (NRC, 1998).

Potassium is the third most abundant mineral in the body after calcium and phosphorus, and is the most abundant mineral in muscle tissue. It is involved in electrolyte balance and neuromuscular function. The content of potassium in pig diets is usually adequate. Signs of potassium deficiency include anorexia, rough hair coat, emaciation, inactivity and ataxia (NRC, 1998).

Magnesium

Magnesium is a cofactor in several enzyme systems and is a constituent of bone. The magnesium present in pig diets is usually adequate. Signs of magnesium deficiency include hyperirritability, muscular twitching, reluctance to stand, weak pasterns, loss of equilibrium, and tetany followed by death (NRC, 1998).

Sulphur

Sulphur is an essential element but is present in the diet in adequate amounts, making supplementation unnecessary.

Trace minerals

Six trace minerals have been shown to be needed as supplements in pig diets: iron, copper, zinc, manganese, iodine and selenium. They are needed in very small or trace amounts in the diet, hence the name 'trace minerals'. Subclinical trace mineral deficiencies probably occur more frequently than recognized by pig producers. Some soils are naturally deficient in trace minerals; for instance, areas in North America with a high rainfall resulting in leaching of the soil and selenium deficiency. Consequently selenium deficiencies have been observed in pigs in Asia when fed US-produced maize and soybean meal but not when fed locally grown feed. Feed suppliers are usually aware of deficient (and adequate) levels of the trace minerals present in feedstuffs and will provide trace minerals mixes formulated appropriately.

Several studies have shown that omitting trace minerals from pig diets depresses productivity even when the animals have access to pasture (Conrad *et al.*, 1959; Clawson and Armstrong, 1980). A study in Ohio (Cline and Mahan, 1972) showed that removing trace minerals from growing-finishing pig diets lowered feed intake and gain and that when trace minerals were added back to the diets an immediate growth response occurred. Research by Edmonds and Arentson (2001) showed that deleting trace minerals from the diet of finishing pigs can reduce the growth rate and nutrient concentration of the meat. Ham from pigs without trace mineral supplementation contained a significantly lower copper concentration than from supplemented animals.

Cobalt

Cobalt is a component of the vitamin B_{12} molecule. A deficiency of cobalt has not been found in pigs fed a diet adequate in vitamin B_{12}. Therefore supplementation with this element is unnecessary. It is possible, however, that if dietary vitamin B_{12} is limited, a need for cobalt, for intestinal synthesis of vitamin B_{12}, may be of importance for pigs. Diets containing no ingredients of animal origin (which contain vitamin B_{12}) contain no vitamin B_{12}. Therefore, pigs fed on all-plant diets may require dietary cobalt. In practice many feed manufacturers use a cobalt-iodized salt for all species since cobalt is needed in ruminant diets. This avoids the need to stock separate salt types for ruminant and non-ruminant diets and the inclusion of cobalt provides some insurance in case the pig diet is lacking sufficient vitamin B_{12}.

Copper

Copper is required for the activity of enzymes associated with iron metabolism, elastin and collagen formation, melanin production, and the integrity of the central nervous system. It is required with iron for normal red blood cell formation (haematopoiesis). Copper is also required for bone formation, brain cell and spinal cord structure, the immune response and hair pigmentation. Sow's milk is low in copper and cannot be increased beyond the normal range by supplementation. Copper is therefore included in all trace mineral supplements for pigs. A deficiency of copper leads to poor iron mobilization, abnormal haematopoiesis, keratinization and decreased synthesis of elastin, myelin and collagen, resulting in skin and joint problems. Leg weakness, various types and degrees of leg crookedness, and the incoordination of muscular action also result. A subclinical deficiency causes reduced serum copper and caeroplasmin, a microcytic hypochromic anaemia, aortic rupture and cardiac hypertrophy (NRC, 1998).

Iodine

It has been known for over 100 years that iodine is required for the proper functioning of the thyroid gland and that an iodine deficiency causes goitre. As a result, iodized salt is now used to prevent this disease in humans and animals. Iodine metabolism is greatly influenced by selenium nutrition, thus influencing basal metabolic rate and several physiological processes. Some dietary factors are goitrogenic. Cruciferous plants contain potential goitrogens of the thiouracil type, while brassicas and white clover contain cyanogenetic glycosides that are goitrogenic (Underwood and Suttle, 1999). Canola meal has resulted from the selection of rapeseed that is low in glucosinolate, a common goitrogen. There are also goitrogenic substances in other feeds such as carrots, linseed, cassava, sweet potatoes, lima beans, millet, groundnuts, cottonseed and soybeans, which impair hormone release from the thyroid gland. Goitre can then occur even though the iodine level in the diet may appear to be adequate. A high calcium level in drinking water is also known to reduce iodine absorption and result in goitre, particularly if the dietary iodine level is borderline. Signs of iodine deficiency in piglets born to iodine-deficient sows are thickened skin, puffy neck, hairlessness and bloated appearance (NRC, 1998). Some of the piglets may be born dead or weak. At necropsy, the thyroid is enlarged and haemorrhagic. Most feedstuffs contain only low levels of iodine. The exception is seaweed, which can contain 4000–6000 mg iodine/kg.

Iron

Most of the iron in the body is in the form of haemoglobin in red blood cells and myoglobin in muscle. The remainder is in the liver, spleen and other tissues. Haemoglobin is essential for the proper function of every organ and tissue of the body. Iron also plays a role in other enzymes involved in oxygen transport and the oxidative process. The pig is born with about 47 mg iron in body stores. This supply will last about a week, since it has been estimated that the pig needs 7 mg iron absorbed daily for normal growth. Sow's milk is very low in iron (about 1 mg/kg), whereas the baby pig's iron requirement is 140–150 mg/kg in the total diet. It is not possible to increase the iron content of milk by increasing the iron supplementation of the sow diet. Therefore, unless the pig is given extra iron, it will become anaemic as early as 5–10 days of age. Thus iron supplementation is very important for the baby pig. The symptoms of iron deficiency include poor growth, listlessness, rough hair coat, anoxia, wrinkled skin, paleness of mucous membranes, hypochromic microcytic anaemia, enlarged heart and spleen, enlarged fatty liver and ascites. A characteristic sign is laboured breathing after minimal activity, from which the term ‘thumps’ arose. Proper iron nutrition is essential for optimum immune function. Blood haemoglobin is a reliable indicator of the iron status of the pig. Usually, a level of less than 9 g haemoglobin/100 ml blood is indicative of anaemia. Organic producers usually provide sods of earth in the farrowing pen for the baby pigs to root. It is important that the sods be free of disease organisms and parasites. Soil contains iron, providing sufficient for piglets raised outdoors on pasture. Iron supplementation of creep-feed and starter diets is necessary for piglets raised outdoors in yards. Diets fed to older animals usually contain adequate levels of iron.

Manganese

Manganese is essential for chondroitin sulphate synthesis, required for the organic matrix of bone. Also, manganese is required to activate enzymes involved in the synthesis of polysaccharides and glycoproteins and it is a key component of pyruvate carboxylase, a critical enzyme in carbohydrate metabolism. Lipid metabolism is also dependent on manganese. Manganese is found in many different feeds; therefore a deficiency is less likely than with most of the other trace minerals. Signs of manganese deficiency include abnormal skeletal growth with an altered ratio of fat to lean body tissue; absence of, or irregular, oestral cycles; poor mammary development and lactation; resorption of fetuses; and, at birth, small weak pigs with a poor sense of balance (NRC, 1998). Decreased growth rate and feed efficiency also occur with manganese deficiency.

Selenium

Selenium is an important part of the enzyme glutathione peroxidase (NRC, 1998). This enzyme destroys peroxides before they can damage body tissues. Vitamin E is also effective as an antioxidant. Therefore, both selenium and vitamin E prevent peroxide damage to body cells. This aids the body’s defence mechanisms against stress. Most feeds contain compounds that can form peroxides. Unsaturated fatty acids are a good example. Rancidity in feeds causes formation of peroxides that destroy nutrients. Vitamin E, for example, is easily destroyed by rancidity. Selenium spares vitamin E by its antioxidant effect. Selenium and vitamin E are therefore interrelated in function. Both are needed by animals and both have metabolic roles in the body in addition to their antioxidant effect. In some instances, vitamin E will substitute in varying degrees for selenium, or vice versa. However, there are deficiency symptoms that respond only to selenium or vitamin E. Although selenium cannot replace vitamin E in nutrition, it reduces the amount of vitamin E required and delays the onset of vitamin E deficiency signs. Selenium plays an important role in increasing the immune response in animals. Sudden death is a common finding with selenium deficiency. Gross necropsy lesions of a selenium deficiency are identical to those of a vitamin E deficiency (NRC, 1998) and include massive hepatic necrosis and oedema of the spiral colon, lungs, subcutaneous tissues and sub-mucosa of the stomach. Paleness and dystrophy of the skeletal muscles (white muscle disease) are also common, and damage to the heart muscle (mulberry heart disease) may also be found. Research by Mahan (2000) showed that adding 0.15 or 0.30 mg selenium/kg diet from sodium selenite from late gestation to day 14 of lactation increased milk selenium content and serum selenium concentration in nursing pigs compared with unsupplemented controls. The incidence and degree of selenium deficiency may be increased by environmental stress.

Selenium is generally included in trace mineral premixes. Common sources are sodium selenite and sodium selenate. Selenium yeast is also used in conventional diets. Excess dietary selenium has to be avoided and the various feeds regulations are designed to prevent this occurrence.

Zinc

Zinc is widely distributed throughout the body and is present in many enzyme systems involved in metabolism. It is required for normal protein synthesis and metabolism, and is also a component of insulin so that it functions in carbohydrate metabolism. Zinc absorption is reduced with diets high in calcium or phytate. Signs of zinc deficiency are reduced appetite and growth rate, skin lesions (parakeratosis) similar to mange, diarrhoea, vomiting, and death in severe cases (NRC, 1998). The skin reddens and dark, watery scabs develop. Borderline deficiencies result in decreased appetite and growth in some animals, while others may show a fading or bleaching of the hair coat. A decrease in litter size and weight of pigs occurs with the sow, and retarded testicular development occurs with the growing boar. Zinc is also important in relation to immune function. A pig with parakeratosis responds very quickly and dramatically to zinc supplementation. Appetite increases immediately and an improvement in skin condition and weight gain occurs within a few days. The zinc in soybean meal, cottonseed meal, sesame meal and other plant protein supplements has low availability, due to the presence of phytate in the feedstuffs which combines with zinc to form zinc phytate. This compound is insoluble in the intestinal tract and cannot be absorbed. Therefore, the zinc in plant protein concentrates is less available than in animal protein supplements such as fishmeal, which contains no phytate. For example, the zinc requirement of the pig fed soybean meal is 50 mg/kg, whereas it is 18 mg/kg for pigs fed casein (animal protein) as the source of protein in the diet (NRC, 1998).

Vitamins

Vitamins are organic (carbon-containing) compounds required for normal growth and the maintenance of animal life. The absence of a given vitamin from the diet, or its impaired absorption or utilization, results in a specific deficiency disease or syndrome.

A commonly accepted definition of a vitamin is an organic compound which:

- is a component of natural food or feed but is distinct from carbohydrate, fat, protein and water;
- is present in feedstuffs in minute quantities;
- is essential for development of normal tissue and for health, growth and maintenance;
- when absent from the diet, or not properly absorbed or utilized, results in a specific deficiency disease or syndrome; and
- cannot be synthesized by the animal and therefore must be obtained from the diet.

There are exceptions to the above. Most or all vitamins can be synthesized chemically. Vitamin D can be synthesized in the skin of animals by exposure to ultraviolet irradiation, and nicotinic acid (niacin) can be synthesized in the body from the AA tryptophan.

Although vitamins are required in small amounts, they serve essential functions in maintaining normal growth and reproduction. Few vitamins can be synthesized by the pig in sufficient amounts to meet its needs. Some are found in adequate amounts in the feedstuffs commonly used in pig diets, others must be supplemented. Although the total amount of a vitamin may appear to be adequate, some vitamins are present in bound or unavailable forms in feedstuffs. Supplementation is then essential.

Classification of vitamins

Vitamins are either fat-soluble or water-soluble and are commonly classified in this way. Vitamin A was the first vitamin discovered and is fat-soluble. Others were later discovered in this group: vitamins D, E and K. Being fat-soluble these vitamins are absorbed into the body with dietary fat, by similar processes. Their absorption is influenced by the same factors that govern fat absorption.

Fat-soluble vitamins can be stored in appreciable quantities in the animal body. When they are excreted from the body they appear in the faeces.

The first water-soluble vitamin discovered was called vitamin B to distinguish it from vitamin A. Later other B vitamins were discovered and given names such as vitamin B_1, B_2, etc. Subsequently the specific chemical names became used. In distinction to the fat-soluble vitamins, the water-soluble vitamins are not absorbed with fats and they are not stored in appreciable quantities in the body (with the possible exception of B_{12} and thiamin). Excesses of these vitamins are excreted rapidly in urine, requiring a constant dietary supply. Characteristics of the different vitamin types are listed in Table 3.4.

Pigs require 14 vitamins (Table 3.5), but not all have to be provided in the diet.

Vitamin A

Either vitamin A or a precursor must be provided in the diet. This vitamin occurs in various forms or vitamers: retinol (alcohol); retinal (aldehyde); retinoic acid; and vitamin A palmitate (ester). Relative activity is measured in international units (1 IU = 0.3 μg retinol) or retinol equivalents (1 RE = 1 μg retinol). Vitamin A has essential roles in vision, bone and muscle growth, reproduction, and maintenance of healthy epithelial tissue. Naturally occurring precursors of vitamin A are found in leafy green vegetables and forages such as lucerne. The common form of the precursor is β-carotene, which can be converted into vitamin A in the intestinal wall. Carotene is present in considerable quantities in pasture, lucerne hay or meal, and yellow maize. Carotene and vitamin A are rapidly destroyed by exposure to air, light and rancidity, especially at high temperature. Since it is difficult to assess the amount present in the feed, diets should be supplemented.

Some fish and animal products, especially liver, milk and milk products and fats, may contain high levels of vitamin A or carotene, reflecting the levels of carotenoids or vitamin A present in the diets of those animals.

Inadequate vitamin A intake may result in reduced feed intake, oedema, eye conditions such as lacrimation and xerophthalmia, nyctalopia (night blindness), slow growth, low conception rate, abortion, stillbirth, blindness at birth, abnormal semen quality, reduced libido, susceptibility to respiratory and other infections and, ultimately, death (NRC, 1998). Only nyctalopia has been shown to be unique to vitamin A deficiency. Deficiency symptoms in growing pigs are unthrifty appearance, poor coordination and various eye abnormalities. Instances of sows failing to breed or producing dead, weak or deformed piglets should be investigated further for vitamin A deficiency. Vitamin A deficiency in boars results in sterility.

Table 3.4. Summary of characteristics of fat-soluble and water-soluble vitamins.

	Fat-soluble	Water-soluble
Chemical composition	C, H, O only	C, H, O+N, S and Co
Occurrence in feeds	Provitamins or precursors may be present	No precursors known (except tryptophan can be converted to niacin)
Function	Specific roles in structural units	Energy transfer. All are required in all cells, as coenzymes
	Exist as several similar compounds	One exact compound
Absorption	Absorbed with fats	Simple diffusion
Storage in body	Substantial; primarily in liver, adipose tissue. Not found in all tissues	Little or no storage (except vitamin B_{12} and possibly thiamin)
Excretion	Faecal (exclusively)	Urinary (mainly). Bacterial products may appear in faeces
Importance in diet	All animals	Non-ruminants only (generally)
Grouping	A, D, E, K	B complex, C, choline

Table 3.5. Vitamins required by pigs.

Fat-soluble	Water-soluble
Vitamin A[a]	Biotin[a]
Vitamin D (D_2 or D_3)[a]	Choline[a]
Vitamin E[a]	Folacin[a]
Vitamin K	Niacin[a]
	Pantothenic acid[a]
	Riboflavin[a]
	Pyridoxine
	Thiamin
	B_{12} (cobalamin)[a]
	Vitamin C (ascorbic acid)

[a]Supply requirement in premix.

Vitamins D, E and K

Like other fat-soluble vitamins, vitamin D is absorbed in the gut with other lipids. The two major natural sources of vitamin D are cholecalciferol (vitamin D_3, the animal form) and ergocalciferol (vitamin D_2, the plant form). The natural source of vitamin D for newborn pigs is sow's milk. Most feedstuffs, except for sun-cured hays, are low in this vitamin and therefore supplementation becomes necessary, especially during winter. Vitamin D can be synthesized in the body by the action of sunlight on a precursor (7-dehydrocholesterol) in the skin, which in summer can provide the entire requirement for vitamin D in animals housed outdoors. Latitude and season affect both the quantity and quality of solar radiation reaching the earth's surface, especially in the ultra violet region of the spectrum. Studies (Webb *et al.*, 1988) have shown that 7-dehydrocholesterol in human skin exposed to sunlight on cloudless days in Boston (42.2°N) from November to February produced no previtamin D_3. In Edmonton (52°N) this ineffective winter period extended from October to March. Further south (34°N and 18°N), sunlight effectively photoconverted 7-dehydrocholesterol to previtamin D_3 in the middle of winter. Presumably a similar situation prevails in the southern hemisphere.

These results demonstrate the dramatic influence of changes in solar radiation on vitamin D_3 synthesis in skin and indicate the effect of latitude on the length of the 'vitamin D winter' during which dietary supplementation of the vitamin is necessary for animals housed outdoors. Organic pig producers need to be aware of these findings. Without supplementation there is a seasonal fluctuation in body stores of the vitamin in animals housed outdoors, requiring dietary supplementation during winter.

Lack of photoproduction of vitamin D or inadequate dietary supplementation of vitamin D leads to a failure of bones to calcify normally. Deficiency signs in young pigs include rickets, stiffness and enlargement of joints, and loss of appetite (NRC, 1998). In older pigs, the bones tend to fracture more easily. Sows give birth to dead or weak piglets. Once this deficiency was recognized, dietary supplementation with vitamin D became common practice. One international unit (IU or ICU) of vitamin D is defined as being equivalent to the activity of 0.025 μg crystalline D_3.

Vitamin E is required for normal reproduction and growth. The most important natural source is α-tocopherol found in plant oils and seeds. The ester form of the vitamin can be synthesized and is used for feed supplementation. One international unit (IU) is defined as being equivalent to the activity of 1 mg DL-α-tocopherol acetate.

The nutritional role of vitamin E is closely interrelated with that of selenium and is involved mainly in the protection of lipid membranes such as cell walls from oxidative damage. Deficiency signs include reproductive failures, cell damage and muscular lesions, causing nutritional muscular dystrophy, mulberry heart disease, hepatosis dietetica, and a brownish-yellow discoloration of fat tissue (NRC, 1998). Although these signs are similar to those of selenium deficiency, it is not possible to substitute selenium for vitamin E. Both nutrients are required in the diet.

Vitamin K occurs naturally in various forms: phylloquinone (K_1) in plants and menaquinone (K_2) which is synthesized in the gut by microbes. Vitamin K is involved in the synthesis of prothrombin (NRC, 1998), a blood clotting factor, hence its name as the coagulation or anti-haemorrhagic vitamin. If deficient, haemorrhaging occurs from the navel at birth and from the castration wound. In some cases, haemorrhaging occurs without causing death. Supplementation of the sow feed with vitamin K will correct the problem, but generally a bleeding problem is not encountered and a dietary supplement of this vitamin is not required.

Water-soluble (B) vitamins

Eight B vitamins are important in pig nutrition. In general they participate in biochemical reactions as enzyme cofactors that mostly affect the transfer of energy. The involvement of B vitamins in diseases of pigs was reviewed by Blair and Newsome (1985).

Biotin plays a role in the synthesis of lipids and in glucose metabolism. Pig diets in regions using wheat as the main cereal source commonly require supplementation (Western Canada, Australia, Scandinavia). Good sources of this vitamin include groundnut meal, safflower meal, yeasts, lucerne meal, cottonseed meal, fishmeal and soybean meal. Clinical signs of biotin deficiency are dermatitis, cracking of soles and hooves, spastic paralysis of the hind legs, decreased rate of gain and poor reproductive performance (NRC, 1998).

Choline is not a vitamin in the strict sense, but is generally included in the water-soluble group (NRC, 1998). It is a structural component of cells and is involved in nerve impulses. Animals synthesize it but this process is often inefficient in young animals, making supplementation advisable. It is contained in some feed ingredients. Many feed companies supplement diets with choline on a regular basis. Choline has been found to prevent a spraddle or splay-leg condition in baby pigs fed purified diets, but generally other factors are involved in practice and taping the hind legs together for a few hours to act as a splint and assisting the baby pig to suckle will correct the condition.

Cobalamin (vitamin B_{12}) is closely related to folic acid in its metabolism. All plants, fruits, vegetables and grains are devoid of this vitamin. Microorganisms produce all of the cobalamin found in nature. Any occurring in plant materials is the result of microbial contamination. Therefore pig diets containing no animal products require supplementation. Deficiency signs include a characteristic anaemia (macrocytic and hyperchromic), reduced growth, poor reproduction and increased mortality (NRC, 1998).

Folacin (folic acid) is involved in the metabolism of single-carbon fragments and in the biosynthesis of purine and pyrimidines. Folic acid is very stable but does not occur naturally in feedstuffs. Instead it occurs in reduced forms as polyglutamate, which are readily oxidized. These forms are converted to folic acid in the body. Diets commonly contain sufficient folacin but some pig diets may be inadequate. Deficiency signs include a characteristic anaemia (macrocytic and hyperchromic), reduced antibody response and poor reproduction (NRC, 1998).

Niacin (nicotinic acid) is a constituent of two coenzymes (NAD and NADP). It is often deficient in diets because cereal grains contain niacin in a form mostly unavailable to the pig. Legumes are good sources. This vitamin can be synthesized in the animal from tryptophan, but the efficiency of conversion is low. Signs of niacin deficiency include a rough skin condition and diarrhoea (NRC, 1998). Ulcers may be found in the mouth.

Pantothenic acid is a component of coenzyme A in the animal body. Diets are often deficient in this vitamin since cereal grains and plant proteins are a poor source of this vitamin. A deficiency can result in an uncoordinated gait (commonly referred to as ‘goose-stepping’), as well as diarrhoea and poor growth rate (NRC, 1998).

Pyridoxine is a component of several enzyme systems involved in nitrogen metabolism. In general diets provide an adequate amount, in the free form or combined with phosphate. Deficiency signs include convulsions and a reduced antibody response (NRC, 1998). Some feedstuffs such as linseed and certain varieties of beans may contain pyridoxine antagonists. Pyridoxine is one vitamin that suffers during feed processing; 70–90% of the content in wheat is lost during milling (Nesheim, 1974).

Riboflavin is required as a component of two coenzymes (FAD and FMN). Diets are often deficient in this vitamin since cereal grains and plant proteins are poor sources of riboflavin. Milk products are good sources of riboflavin. Signs of deficiency in growing pigs include loss of appetite, rough hair, vomiting, inability to stand normally and slow growth rate. In sows, signs are poor conception rates and the birth of weak or dead pigs (NRC, 1998).

Thiamin is important as a component of the coenzyme thiamin pyrophosphate (cocarboxylase). Good sources are lucerne, grains and yeast. Deficiencies (NRC, 1998) are less frequently encountered than deficiencies of other vitamins.

Ascorbic acid (vitamin C) is a water-soluble vitamin but is not part of the B-vitamin group. It is a metabolic requirement for all species but is a dietary requirement only for those that lack the enzyme for its synthesis (primates, guinea pigs, certain birds, fish). It is involved in the formation and maintenance of intercellular tissues having collagen or related substances as basal constituents. Deficiency signs include haemorrhage, swollen and bleeding gums, anaemia and loosening of the teeth (scurvy).

Response to signs of vitamin deficiency

Vitamin deficiency signs are rarely specific. Thus if a deficiency of vitamin A, D or E is suspected it is advisable to check with a veterinarian and administer all three by supplementing the feed or the drinking water (using a water-miscible form). If a B-vitamin deficiency is suspected it is advisable to check with a veterinarian and administer a B-vitamin complex by supplementing the feed or preferably the drinking water, since these vitamins are water-soluble and since pigs do not eat well when deficient in B vitamins. The prevailing organic standards may permit injection of vitamins to correct deficiencies, but this should be checked with the certifying agency.

Water

Water is also a required nutrient, the requirement being about 2–3 times the weight of feed eaten. The most important consideration with pigs is to ensure that there is an adequate supply of fresh, uncontaminated water available at all times. Water should always be available *ad libitum*, from water bowls or nipples (bowls are easier to check, nipples are cleaner). Water quality is important. The general guidelines are based on total dissolved solids, with pH between 6 and 8. Some specific salts are important. Common guidelines specify sulphates up to 700 mg/l for weanlings; nitrates up to 440 mg/l; and nitrites up to 33 mg/l.

Feed Analysis

A feedstuff or diet can be analysed chemically to provide information on the contents of the components discussed above. Generally this does not provide information on the amount of the nutrient that is biologically available to the animal.

Proximate (approximate) analysis is a scheme developed originally in 1865 by Henneberg and Stohmann of the Weende Experiment Station in Germany to analyse the main components of feedstuffs. It is often referred to as the Weende system and has been refined over time. The system consists of determinations of water (moisture), ash, crude fat (ether extract), crude protein (CP) and crude fibre (CF). It attempts to separate carbohydrates into two broad classifications, CF (indigestible carbohydrate) and nitrogen-free extract (NFE; digestible carbohydrate). NFE is measured by difference rather than by direct analysis.

The information gained is as follows:

1. *Moisture (water)*: This can be regarded as a component that dilutes the content of nutrients and its measurement provides more accurate information on nutrient contents.
2. *Dry matter* (DM): This is the amount of dry material present after the moisture (water) content has been deducted.
3. *Ash*: This provides information on mineral content. Further analyses can provide

exact information on specific minerals present, such as calcium or sodium.

4. *Organic matter*: This is the amount of protein and carbohydrate material present after ash has been deducted from DM.

5. *Crude protein*: This is determined as nitrogen content × 6.25. It is a measure of protein present, based on the assumption that the average nitrogen content is 16 g N/100 g protein. Some of the nitrogen in common feedstuffs is present as non-protein nitrogen (NPN) and, therefore, the value calculated by multiplying nitrogen content by 6.25 is referred to as crude rather than true protein. True protein is made up of AA, which can be measured using specialized techniques.

6. *Non-nitrogenous material*

6.1 *Fibre*: obtained as CF. Part of this fraction is digestible; therefore more exact methods of fibre analysis were later developed by Van Soest and associates for use mainly in cattle, sheep and goat feeding since these species subsist largely on forages. The advanced procedure separates the fibre into two fractions: (i) plant cell contents, a highly digestible fraction consisting of sugars, starches, soluble protein, pectin and lipids (fats); and (ii) plant cell wall constituents, a fraction of variable digestibility consisting of insoluble protein, hemicellulose, cellulose, lignin and bound nitrogen. The method involves boiling a sample in a neutral detergent solution. The soluble fraction is termed neutral-detergent solubles (NDS; cell contents) and the fibrous residue is called neutral-detergent fibre (NDF; cell wall constituents). Unlike CF and NFE, both NDS and NDF accurately predict the proportions of more and less digestible fractions, respectively, found in a wide variety of feedstuffs.

A second method is the acid-detergent fibre (ADF) analysis, which breaks down NDF into a soluble fraction containing primarily hemicellulose and some insoluble protein and an insoluble fraction containing cellulose, lignin and bound nitrogen. Lignin has been shown to be a major factor influencing the digestibility of forages.

Tables of feedstuff composition for pigs increasingly quote NDF and ADF values rather than CF values, since these data are being used by pig nutritionists. It is important to note, however, that CF is still the fibre component required by feed regulatory authorities to be stated on the feed label of purchased feed, at least in North America.

6.2 *Nitrogen-free extract*: the digestible carbohydrates, i.e. starch and sugars.

7. *Fat*: measured as crude fat (sometimes called oil or ether extract since ether is used in the extraction process). More detailed analyses can be done to measure individual fatty acids.

Vitamins are not measured directly in the Weende system, but can be measured in the fat- and water-soluble extracts by appropriate methods.

Eventually, rapid methods based on techniques such as near infra-red reflectance spectroscopy (NIRS) are expected to replace chemical methods for routine feed analysis, but bioavailability is expected to continue to be based on data from animal studies.

Publications on Nutrient Requirements

Nutrient requirements in North America are based on the recommendations of the National Research Council, National Academy of Sciences, Washington, DC. The recommendations cover pigs, poultry, dairy cattle, horses, laboratory animals, etc., and are published as a series of books. The recommendations for each species are updated periodically, the current *Nutrient Requirements of Swine* 2012, *11th revised edition* (NRC, 2012) being the most up to date. The information is used widely by the feed industry in North America and in many other regions. Although this edition could be used in deriving standards for organic diets, the estimated requirements were unchanged from the 1998 version. Since the 1998 version is more user-friendly for the average producer, this version is more appropriate for use in organic production.

No comparable recommendations exist in other countries. UK nutrient requirement standards were prepared in the past by national committees, e.g. the Agricultural Research Council (ARC, 1981) and the Agricultural and Food Research Council (AFRC, 1990, 1991), but they have not been updated recently for all classes of pig. Reviews on energy and protein requirements of breeding and growing pigs have been published (Whittemore *et al*., 2001a,b,c) and it has been suggested that similar reviews on vitamin and mineral requirements are needed. The Netherlands uses official standards published by the Dutch Centraal Veevoeder Bureau (CVB, 2000) covering mainly feed composition tables for energy, AA (with availabilities) and major minerals. Use is also made in The Netherlands of ARC (1981) and NRC (1998) especially for mineral and vitamin requirements. Denmark has a National Standard for the nutrient requirements of pigs covering all nutrients to be provided to all the various classes of pig. The standard is reviewed and revised regularly. The Danish information base may be of limited use elsewhere because of the way in which energy and protein requirements are expressed and differences in feed evaluation methodology. The most recent French publication on requirements is that of the Institut National de la Recherche Agronomique (INRA) in 1984, which covers pigs, poultry and rabbits. There are no national standards for the nutrient requirements of pigs in Spain. The official standard most widely accepted there is NRC (1998). Australian nutritional standards are now out of date, with ARC (1981) and those of the Standing Committee on Agriculture (SCA, 1987) being used in the past. As a result there is no national set of recommendations and no good up-to-date information specifically developed and available for Australia.

One of the limitations of published estimates of requirements is their applicability generally. For instance, a main issue influencing nutrient requirements for energy and AA in the growing pig is the capacity for the genotype in question to lay down fat as the animal grows to maturity. Responses to higher dietary concentrations of AA will be positive only in animals with a genetic potential to deposit lean tissue rather than fat. As a result, it is not possible to establish nutritional standards for AA that can be applied generally. For this reason, the feed industry in Europe, Australia and to some extent North America now uses nutrient requirement models based on requirement data but tailored to specific genotypes of pig.

There is currently no set of nutritional standards designed specifically for organic pigs. These standards will have to be derived from existing standards for commercial pigs.

One of the criticisms of the NRC publications is that some of the data are old and out-of-date because the research in question was carried out some time ago. Also, that the time lag in the derivation of new research findings, its peer-review and publication in scientific journals, and its incorporation into the NRC recommendations, makes the information less applicable to superior genotypes of pigs. However, this criticism is of less importance to organic producers. Most organic producers use traditional breeds of pig that have not been subjected to the selection pressure imposed on leading genotypes used in conventional production. Consequently they should find the NRC publications a useful guide to nutrient requirements. Furthermore it could be argued that, of the various requirement estimates available, the ARC (1981) and SCA (1987) estimates are the most applicable to organic production because of the genotypes used in deriving them. The data are, however, incomplete. It is debatable whether requirement tables such as those produced by NRC, ARC and SCA are applicable in developing countries. For instance, Preston and Leng (1987) have argued that in developing countries the objective should be to optimize the use of available resources and minimize the use of imported ingredients. Under these conditions it is very difficult to achieve NRC, ARC or SCA requirements economically and optimal production is, as a result, less than maximal.

The present publication takes the view that the NRC recommendations are of primary interest to organic pig producers worldwide. The Australian (SCA, 1987) feeding standards, which are based on the ARC (1981) recommendations but are more complete, are also of interest. In addition, pig producers in Australia use genotypes based on traditional European breeds that are being used in many countries for organic production. One valuable aspect of the Australian standards is that the requirements have been extrapolated using modelling methods into a series of tables setting out nutrient needs in a range of pigs varying in weight and genotype. Producers can then select which model best fits their situation. This modelling approach is now the one adopted by authorities engaged in establishing standards, the NRC (2012) publication setting out the appropriate methodology.

Although a great deal of new research had been published during the preceding 15 years, the NRC (2012) concluded that for many nutrients there was little or no new research data on requirements. Consequently the nutrient requirement values published in the 10th edition (1998) were retained. Accordingly, the nutrient requirements set out in Tables 3.6 and 3.7 below (from NRC, 1998) are suggested as the basis for the establishment of nutritional standards applicable in average herds of organic pigs, the animals being genotypes drawn from traditional breeds. On the other hand, organic producers using modern hybrids may find the requirement values recommended by the breeding company for that particular genotype to be more useful than the values suggested here.

Derivation of standards

Standards can be derived from the above data for application by producers and by the feed industry. Application of the standards is aimed at providing a balanced diet, the features of which can be outlined as follows:

Fig. 3.3. Nature's best food. (Courtesy of David Fraser.)

- The DE (or ME) level is correct for the class of pig in question.
- The CP is at the correct level in relation to DE (or ME).
- The EAA requirements on a bioavailable basis have been met and the balance of AA is appropriate.
- Sufficient minerals have been added to meet the requirements for
  - macro minerals;
  - trace minerals.
- Sufficient vitamins have been added to meet requirements.
- The diet contains no dangerous excesses of nutrients or deleterious compounds.

In addition it is desirable to ensure that suitable ingredients have been selected and that they have been mixed to produce a uniform diet. This aspect is outlined in Chapter 5.

Table 3.6. Estimated nutrient requirements of breeding pigs, amount per kg diet (90% moisture basis) (from NRC).

	Bred gilts, sows			Lactating gilts, sows			Boars		
	1979	1988	1998[a]	1979	1988	1998[a]	1979	1988	1998
Digestible energy (kcal/kg)	3400	3340	3400	3395	3340	3400	3400	3340	3400
Digestible energy (MJ/kg)	14.23	13.97	14.23	14.2	13.97	14.23	14.23	13.97	14.23
Metabolizable energy (kcal/kg)	3200	3210	3265	3195	3210	3265	3200	3210	3265
Metabolizable energy (MJ/kg)	13.39	13.43	13.66	13.37	13.43	13.66	13.39	13.43	13.66
Crude protein (g/kg)	120	120	128	130	130	185	120	120	130
Amino acids (g/kg)									
Arginine	NA	NA	0.3	4.0	4.0	4.9	NA	NA	NA
Histidine	1.5	1.5	1.8	2.5	2.5	3.8	1.5	1.5	1.9
Isoleucine	3.7	3.0	3.2	3.9	3.9	5.4	3.7	3.0	3.5
Leucine	4.2	3.0	4.9	7.0	4.8	10.5	4.2	3.0	5.1
Lysine	4.3	4.3	5.7	5.8	6.0	9.7	4.3	4.3	6.0
Available lysine	NA	NA	4.9	NA	NA	8.5	NA	NA	NA
Methionine + cysteine	2.3	2.3	3.8	3.6	3.6	4.7	2.3	2.3	4.2
Phenyalanine + tyrosine	5.2	4.5	5.4	8.5	7.0	10.8	5.2	4.5	5.7
Threonine	3.4	3.0	4.5	4.3	4.3	6.3	3.4	3.0	5.0
Tryptophan	0.9	0.9	1.1	1.2	1.2	1.8	0.9	0.9	1.2
Valine	4.6	3.2	3.8	5.5	6.0	8.3	4.6	3.2	4.0
Minerals (g/kg)									
Calcium	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Phosphorus (total)	6.0	6.0	6.0	5.0	6.0	6.0	6.0	6.0	6.0
Phosphorus (available)	NA	3.5	3.5	NA	3.5	3.5	NA	3.5	3.5
Chloride	2.5	1.2	1.2	3.0	1.6	1.6	2.5	1.2	1.2
Magnesium	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Potassium	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Sodium	1.5	1.5	1.5	2.0	2.0	2.0	1.5	1.5	1.5
Trace minerals (mg/kg)									
Copper	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Iodine	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Iron	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
Manganese	10.0	10.0	20.0	10.0	10.0	20.0	10.0	10.0	20.0
Selenium	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Zinc	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0

Vitamins (IU/kg)									
Vitamin A	4000	4000	4000	2000	2000	2000	4000	4000	4000
Vitamin D	200	200	200	200	200	200	200	200	200
Vitamin E	10.0	22.0	44.0	10.0	22.0	44.0	10.0	22.0	44.0
Vitamins (mg/kg)									
Biotin	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.2
Choline	1250	1250	1250	1250	1000	1000	1000	1250	1250
Folacin	0.6	0.3	1.3	0.6	0.3	1.3	0.6	0.3	1.3
Niacin	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Pantothenic acid	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Pyridoxine	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Riboflavin	3.0	3.75	3.75	3.0	3.75	3.75	3.0	3.75	3.75
Thiamin	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Vitamins (μg/kg)									
Cobalamin (B_{12})	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Linoleic acid (g/kg)	NA	1.0	1.0	NA	1.0	1.0	NA	1.0	1.0

NA, not available.

[a]Based on weight at breeding of 150 kg, gestation weight gain of 45 kg, 12 pigs in litter, post-farrowing weight of 175 kg, 10 kg weight loss during lactation, and average piglet weight gain of 200 g/day.

Table 3.7. Estimated nutrient requirements of growing-finishing pigs fed *ad libitum*, amount per kg diet (90% moisture basis) (from NRC).

	Live weight (kg)								
	10–20			20–50			50–100		
	1979	1988	1998	1979[a]	1988	1998	1979[b]	1988	1998
Digestible energy (kcal/kg)	3370	3400	3400	3390	3400	3400	3395	3400	3400
Digestible energy (MJ/kg)	14.10	14.23	14.23	14.12	14.23	14.23	14.20	14.23	14.23
Metabolizable energy (kcal/kg)	3160	3250	3265	3190	3260	3265	3195	3275	3265
Metabolizable energy (MJ/kg)	13.22	13.60	13.65	13.35	13.61	13.65	13.37	13.70	13.65
Crude protein (g/kg)	180	180	209	140	150	180	130	130	140
Amino acids (g/kg)									
Arginine	2.3	4.0	4.6	1.8	2.5	3.7	1.6	1.0	2.2
Histidine	2.0	2.5	3.6	1.6	2.2	3.0	1.5	1.8	2.1
Isoleucine	5.6	5.3	6.3	4.4	4.6	5.1	4.1	3.8	3.7
Leucine	6.8	7.0	11.2	5.2	6.0	9.0	4.8	5.0	6.1
Lysine	7.9	9.5	11.5	6.1	7.5	9.5	5.7	6.0	6.6
Available lysine	NA	NA	10.1	NA	NA	8.3	NA	NA	5.7
Methionine + cysteine	5.1	4.8	6.5	4.0	4.1	5.4	3.0	3.4	3.8
Phenylalanine + tyrosine	7.9	7.7	10.6	6.1	6.6	8.7	5.7	5.5	5.9
Threonine	5.1	5.6	7.4	3.9	4.8	6.1	3.7	4.0	4.4
Tryptophan	1.3	1.4	2.1	1.1	1.2	1.7	1.0	1.0	1.2
Valine	5.6	5.6	7.9	4.4	4.8	6.4	4.1	4.3	5.2
Minerals (g/kg)									
Calcium	6.5	7.0	7.0	5.5	6.0	6.0	5.0	5.0	5.0
Phosphorus (total)	5.5	6.0	6.0	4.5	5.0	5.0	4.0	4.0	4.5
Phosphorus (available)	NA	3.2	3.2	NA	2.3	2.3	NA	1.5	1.9
Chloride	1.3	0.8	1.5	1.3	0.8	0.8	1.3	0.8	0.8
Magnesium	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Potassium	2.6	2.6	2.6	2.0	2.3	2.3	1.7	1.7	1.9
Sodium	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0
Trace minerals (mg/kg)									
Copper	5.0	5.0	5.0	3.0	4.0	4.0	3.0	3.0	3.5
Iodine	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Iron	80.0	80.0	80.0	50.0	60.0	60.0	40.0	40.0	50.0
Manganese	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0

Selenium	0.15	0.25	0.25	0.15	0.15	0.15	0.10	0.10	0.15
Zinc	80.0	80.0	80.0	50.0	60.0	60.0	50.0	50.0	50.0
Vitamins (IU/kg)									
Vitamin A	1750	1750	1750	1300	1300	1300	1300	1300	1300
Vitamin D	200	200	200	150	150	150	125	150	150
Vitamin E	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Vitamins (mg/kg)									
Biotin	0.1	0.05	0.05	0.1	0.05	0.05	0.1	0.05	0.05
Choline	900	400	400	550	300	300	400	300	300
Folacin	0.6	0.3	0.3	0.6	0.3	0.3	0.6	0.3	0.3
Niacin	18.0	12.5	12.5	12.0	10.0	10.0	10.0	7.0	7.0
Pantothenic acid	11.0	9.0	9.0	11.0	8.0	8.0	11.0	7.0	7.0
Pyridoxine	1.5	1.5	1.5	1.1	1.0	1.0	1.1	1.0	1.0
Riboflavin	3.0	3.0	3.0	2.2	2.5	2.5	2.2	2.0	2.0
Thiamin	1.1	1.0	1.0	1.1	1.0	1.0	1.1	1.0	1.0
Vitamins (µg/kg)									
Cobalamin (B_{12})	15.0	15.0	15.0	11.0	10.0	10.0	11.0	5.0	5.0
Linoleic acid (g/kg)	NA	1.0	1.0	NA	1.0	1.0	NA	1.0	1.0

NA: not available.
[a]35–60 kg live weight.
[b]60–100 kg live weight.

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4

Approved Ingredients for Organic Diets

New Zealand is one of the few countries to include a list of approved feed ingredients in the organic regulations (Table 4.1). This is a very useful feature of their regulations. In addition, the regulations stipulate that the feeds must meet the ACVM Act and regulations, the HSNO Act, or are exempt, thus providing additional assurance to the consumer. This list appears to be based on the EU list, possibly because of export requirements.

The EU has a somewhat similar list (Table 4.1), but one detailing non-organic feedstuffs that can be used in limited quantities in organic feeds for pigs. It may be inferred from the EU list that organic sources of the named ingredients are acceptable. This list is particularly useful because it is currently very difficult to formulate some feeds that are 100% organic. As a result the regulations in several regions allow for feed to contain up to 10% non-organic ingredients. Should a producer need to take advantage of this provision, it is necessary that approval be obtained from the local certifying agency. The EU list can then be used to select the appropriate ingredients to make up the 10%.

That provision will not be possible after 31 December 2017 when diets for pigs (and poultry) will have to contain 100% organic ingredients.

Most countries follow the EU system and do not publish an approved list of organic feedstuffs, stating that all feedstuffs used must meet organic guidelines.

An example is the USA, where the regulations also state that all feed, feed additives and feed supplements must comply with Food and Drug Administration (FDA) regulations. Canada has a much less detailed Permitted Substances List (CAN/CGSB-32.311-2006) than the New Zealand or EU lists, stating that:

> [E]nergy feeds and forage concentrates (grains) and roughages (hay, silage, fodder, straw) shall be obtained from organic sources and may include silage preservation products (e.g. bacterial or enzymatic additives derived from bacteria, fungi and plants and food by-products [e.g. molasses and whey]). Note that if weather conditions are unfavourable to fermentation, lactic, propionic and formic acid may be used.

Based on the information above, which is drawn from both the northern and southern hemispheres, the present chapter suggests potential feedstuffs available for organic pig production in many countries. Not all of the feed ingredients in Table 4.1 are suitable for inclusion in pig diets, since the lists include those more suited for ruminant feeding. In addition, some of the ingredients are not usually available in sufficient quantity.

One of the questions raised by the publication of lists of approved feed ingredients in organic regulations is how new ingredients

Table 4.1. Comparison of approved organic feedstuffs in New Zealand (NZ) and approved non-organic feedstuffs in the European Union (EU).

	NZ-approved list (only those named in each category) MAF Standard OP3, Appendix Two, 2011 (NZFSA, 2011)	EU-approved list of non-organic feedstuffs (up to defined limits) EC No 834/2007 (European Commission, 2007) and EU 68/2013 (European Commission (2013)
Feed materials from plant origin	• Cereals, grains, their products and by-products. Oats as grains, flakes, middlings, hulls and bran; barley as grains, protein and middlings; rice germ expeller; millet as grains; rye as grains and middlings; sorghum as grains; wheat as grains, middlings, bran, gluten feed, gluten and germ; spelt as grains; triticale as grains; maize as grains, bran, middlings, germ expeller and gluten; malt culms; brewer's grains (rice as grain, rice broken, rice bran, rye feed, rye bran and tapioca were de-listed in 2004)	• Cereals, grains, their products and by-products. Oats as grains, flakes, middlings, hulls and bran; barley as grains, protein and middlings; rice germ expeller; millet as grains; rye as grains and middlings; sorghum as grains; wheat as grains, middlings, bran, gluten feed, gluten and germ; spelt as grains; triticale as grains; maize as grains, bran, middlings, germ expeller and gluten; malt culms; brewer's grains
	• Oilseeds, oil fruits, their products and by-products. Canola (rapeseed) as expeller and hulls; soybean as bean, toasted, expeller and hulls; sunflower seed as seed and expeller; cotton as seed and seed expeller; linseed as seed and expeller; sesame seed as expeller; palm kernels as expeller; pumpkin seed as expeller; olives, olive pulp; vegetable oils (from physical extraction) (turnip rapeseed expeller was de-listed in 2004)	• Oilseeds, oil fruits, their products and by-products. Canola (rapeseed) as expeller and hulls; soybean as bean, toasted, expeller and hulls; sunflower seed as seed and expeller; cotton as seed and seed expeller; linseed as seed and expeller; sesame seed as expeller; palm kernels as expeller; pumpkin seed as expeller; olives, olive pulp (from physical extraction of olives); vegetable oils (from physical extraction)
	• Legume seeds, their products and by-products. Chickpeas as seeds, middlings and bran; ervil as seeds, middlings and bran; chickling vetch as seeds submitted to heat treatment, middlings and bran; peas as seeds, middlings and bran; broad beans as seeds, middlings and bran; horse beans as seeds middlings and bran; vetches as seeds, middlings and bran; lupin as seeds, middlings and bran	• Legume seeds, their products and by-products. Chickpeas as seeds, middlings and bran; ervil as seeds, middlings and bran; chickling vetch as seeds submitted to an appropriate heat treatment, middlings and bran; peas as seeds, middlings and bran; broad beans as seeds, middlings and bran; horse beans as seeds, middlings and bran; vetches as seeds, middlings and bran; lupin as seeds, middlings and bran
	• Tuber roots, their products and by-products. Sugarbeet pulp, potato, sweet potato as tuber, potato pulp (by-product of the extraction of potato starch), potato starch, potato protein, manioc (cassava)	• Tuber roots, their products and by-products. Sugarbeet pulp, potato, sweet potato as tuber, manioc as roots, potato pulp (by-product of the extraction of potato starch), potato starch, potato protein
	• Other seeds and fruits, their products and by-products. Carob, carob pods and meals thereof; pumpkins, citrus pulp, apples, quinces, pears, peaches, figs, grapes and pulps thereof; chestnuts, walnut expeller, hazelnut expeller; cocoa husks and expeller; acorns	• Other seeds and fruits, their products and by-products. Carob, carob pods and meals thereof, citrus pulp, pumpkins; apples, quinces, pears, peaches, figs, grapes and pulps thereof; chestnuts, walnut expeller, hazelnut expeller; cocoa husks and expeller; acorns

Continued

Table 4.1. Continued.

	NZ-approved list (only those named in each category) MAF Standard OP3, Appendix Two, 2011 (NZFSA, 2011)	EU-approved list of non-organic feedstuffs (up to defined limits) EC No 834/2007 (European Commission, 2007) and EU 68/2013 (European Commission (2013)
	• Forages and roughages. Lucerne (alfalfa), lucerne meal, clover, clover meal, grass (obtained from forage plants), grass meal, hay, silage, straw of cereals, root vegetables for foraging	• Forages and roughages. Lucerne, lucerne meal, clover, clover meal, grass (obtained from forage plants), grass meal, hay, silage, straw of cereals, root vegetables for foraging
	• Other plants, their products and by-products. Molasses, seaweed meal (obtained by drying and crushing seaweed and washed to reduce iodine content), powders and extracts of plants, plant protein extracts (solely provided to young animals), spices and herbs	• Other plants, their products and by-products. Molasses, seaweed meal (obtained by drying and crushing seaweed and washed to reduce iodine content), powders and extracts of plants, plant protein extracts (solely provided to young animals), spices and herbs
Feed materials of animal origin	• Milk and milk products. Raw milk, milk powder, skimmed milk, skimmed-milk powder, buttermilk, buttermilk powder, whey, whey powder, whey powder low in sugar, whey protein powder (extracted by physical treatment), casein powder, lactose powder, curd and sour milk	• Milk and milk products. Raw milks (as defined in Article 2 of Directive 92/46/EEC), milk powder, skimmed milk, skimmed milk powder, buttermilk, buttermilk powder, whey, whey powder, whey powder low in sugar, whey protein powder (extracted by physical treatment), casein powder, lactose powder, curd and sour milk
	• Fish, other marine animals, their products and by-products. Fish, fish oil and cod-liver oil not refined; fish molluscan or crustacean autolysates, hydrolysate and proteolysates obtained by an enzyme action, whether or not in soluble form, solely provided to young animals; fishmeal	• Fish, other marine animals, their products and by-products. Fish, fish oil and cod-liver oil not refined; fish molluscan or crustacean autolysates, hydrolysate and proteolysates obtained by an enzyme action, whether or not in soluble form, solely provided to young animals; fishmeal
Feed materials of mineral origin	• Sodium products. Unrefined sea salt, coarse rock salt, sodium sulphate, sodium carbonate, sodium bicarbonate, sodium chloride	• Sodium products. Unrefined sea salt, coarse rock salt, sodium sulphate, sodium carbonate, sodium bicarbonate, sodium chloride Potassium products; potassium chloride
	• Calcium products. Lithotamnion and maerl shells of aquatic animals (including cuttlefish bones), calcium carbonate, calcium lactate, calcium gluconate	• Calcium products. Lithotamnion and maerl, shells of aquatic animals (including cuttlefish bones), calcium carbonate, calcium lactate, calcium gluconate
	• Phosphorus products. Bone dicalcium phosphate precipitate, defluorinated dicalcium phosphate, defluorinated monocalcium phosphate	• Phosphorus products. Defluorinated dicalcium phosphate, defluorinated monocalcium phosphate, monosodium phosphate, calcium-magnesium phosphate, calcium-sodium phosphate
	• Magnesium products. Magnesium sulphate, magnesium chloride, magnesium carbonate, magnesium oxide (anhydrous magnesia)	• Magnesium products. Anhydrous magnesia, magnesium sulphate, magnesium chloride, magnesium carbonate, magnesium phosphate
	• Sulphur products. Sodium sulphate	• Sulphur products. Sodium sulphate

Continued

Table 4.1. Continued.

	NZ-approved list (only those named in each category) MAF Standard OP3, Appendix Two, 2011 (NZFSA, 2011)	EU-approved list of non-organic feedstuffs (up to defined limits) EC No 834/2007 (European Commission, 2007) and EU 68/2013 (European Commission (2013)
Feed additives	Trace elements:	Trace elements:
	E1 Iron products: ferrous carbonate, sulphate monohydrate and/or heptahydrate, ferric oxide	E1 Iron products: ferrous carbonate, ferrous sulphate monohydrate and/or heptahydrate, ferric oxide
	E2 Iodine products: calcium iodate anhydrous, calcium iodate hexahydrate, sodium iodide	E2 Iodine products: calcium iodate anhydrous, calcium iodate hexahydrate, sodium iodide
	E3 Cobalt products: cobaltous sulphate monohydrate and/or heptahydrate, basic cobaltous carbonate monohydrate	E3 Cobalt products: cobaltous sulphate monohydrate and/or heptahydrate, basic cobaltous carbonate monohydrate
	E4 Copper products: copper oxide, basic copper carbonate monohydrate, copper sulphate pentahydrate	E4 Copper products: copper oxide, basic copper carbonate monohydrate, copper sulphate pentahydrate
	E5 Manganese products: manganous carbonate, manganous oxide, manganous sulphate mono- and/or tetrahydrate	E5 Manganese products: manganous carbonate, manganous oxide, manganic oxide, manganous sulphate mono- and/or tetrahydrate
	E6 Zinc products: zinc carbonate, zinc oxide, zinc sulphate mono- and/or heptahydrate	E6 Zinc products: zinc carbonate, zinc oxide, zinc sulphate mono- and/or heptahydrate
	E7 Molybdenum products: ammonium molybdate, sodium molybdate	E7 Molybdenum products: ammonium molybdate, sodium molybdate
	E8 Selenium products: sodium selenate, sodium selenite	E8 Selenium products: sodium selenate, sodium selenite
Vitamins and provitamins	Vitamins approved for use under NZ legislation: preferably derived from ingredients occurring naturally in feeds, or synthetic vitamins identical to natural vitamins only for non-ruminant animals. When the organic feed or organic pork product is to be exported to the USA, the vitamins and trace minerals used have to be FDA-approved	Vitamins, provitamins and chemically well-defined substances having a similar effect. Vitamins authorized under Directive 70/524/EEC: preferably derived from raw materials occurring naturally in feedingstuffs, or synthetic vitamins identical to natural vitamins (only for non-ruminant animals)
Enzymes	Enzymes approved for use under NZ legislation	Enzymes authorized under Directive 70/524/EEC
Microorganisms	Microorganisms approved for use under NZ legislation	Microorganisms authorized under Directive 70/524/EEC
Preservatives	E236 Formic acid	E200 Sorbic acid
	E260 Acetic acid	E236 Formic acid
	E270 Lactic acid	E260 Acetic acid
	E280 Propionic acid	E270 Lactic acid
		E280 Propionic acid
		E330 Citric acid
Binders, anti-caking agents and coagulants	E551b Colloidal silica	E470 Calcium stearate of natural origin
	E551c Kieselgur	E551b Colloidal silica
	E558 Bentonite	E551c Kieselgur

Continued

Table 4.1. Continued.

	NZ-approved list (only those named in each category) MAF Standard OP3, Appendix Two, 2011 (NZFSA, 2011)	EU-approved list of non-organic feedstuffs (up to defined limits) EC No 834/2007 (European Commission, 2007) and EU 68/2013 (European Commission (2013)
	E559 Kaolinitic clays E561 Vermiculite E562 Sepiolite E599 Perlite	E553 Sepiolite E558 Bentonite E559 Kaolinitic clays E560 Natural mixtures of stearites and chlorite E561 Vermiculite E562 Sepiolite E599 Perlite
Antioxidant substances	E306 Tocopherol-rich extracts of natural origin	E306 Tocopherol-rich extracts of natural origin
Certain products used in animal nutrition	Brewer's yeasts	Brewer's yeast
Processing aids for silage	Sea salt, coarse rock salt, whey, sugar, sugarbeet pulp, cereal flour and molasses	Sea salt, coarse rock salt, whey, sugar, sugarbeet pulp, cereal flour, molasses
Pure amino acids	None	None

FDA, Food and Drug Administration.
Maize as bran is listed twice in the NZ and EU regulations, probably a typographical error – corrected above.

are added. An example is lentils, which can be grown organically (mainly for the human market) and are available in some countries for pig feeding. Therefore the following contains feed ingredients that are not included in Table 4.1 but meet the criteria for inclusion in organic diets. Another interesting question is whether fish products such as fishmeal are organic in the conventional sense. Fortunately they are accepted as such since they are valuable sources of amino acids, particularly when pure amino acids are not permitted. However, they have to be from sustainable sources and any antioxidant added to prevent spoilage has to be from the approved list.

Although the New Zealand and EU regulations state that pure amino acids such as lysine and methionine are not allowed in organic feed, the regulations in several regions allow a temporary usage of these feed additives to improve the quality of the protein. For instance, Canada has banned the use of amino acids from non-synthetic sources only but has granted an exception for the use of synthetic DL-methionine, DL-methionine-hydroxy analogue and DL-methionine-hydroxy analogue calcium in poultry diets, with this exception to be re-evaluated at the next revision of the Canadian standard. Currently the Canadian provinces of Quebec and British Columbia allow pure amino acids in organic diets, a distinction being made between those of fermented origin (approved, e.g. lysine) and those of synthetic origin (prohibited, e.g. methionine).

Another example of a new feedstuff that might be acceptable in organic feeds is insect larval meal, which is being produced in several countries from substrates such as household food waste. Some certifying agencies take the view that the meal produced is a permissible ingredient (and a good source of protein) in organic feed, while others take the view that the insect meal is unacceptable as an organic feed ingredient since the substrate used cannot be verified as organic. Producers planning to use this type of product should, therefore, obtain approval from a local certifying agency before doing so.

The status of other products such as potato protein could be questioned as being organic in the conventional sense, as they are industrial by-products and may have been produced from conventionally-grown rather than organic potatoes. Again, their inclusion in approved lists of organic feed ingredients is fortunate since they too are valuable sources of amino acids. Their designation as organic may therefore be based on expediency rather than organic principles.

Approved lists are also open to interpretation. An example is calcium carbonate, an approved organic source of calcium. Is ground limestone, a natural and common source of calcium carbonate and prepared from mined calcareous rock, approved as 'calcium carbonate'? It is a well-established ingredient in conventional pig diets and one assumes that it is acceptable in organic diets. In cases such as this the producer should verify with the certifying agency that this interpretation is correct. This example adds weight to the conclusion of Wilson (2003) that it would be very helpful if lists of approved feedstuffs could be very specific.

The nutritional characteristics and recommended inclusion rates of the feedstuffs which are considered most likely to be used in organic pig diets are set out below. Each feed is listed with its International Feed Number (IFN) since some feedstuffs are known under several common names internationally. Professor Lorin Harris, Director of the International Feedstuffs Institute at Utah State University, devised the International Feed Vocabulary to overcome confusion in naming feeds. The system is used by the National Research Council (NRC) in their publications to identify feedstuffs correctly and by scientific agencies in several countries.

In this system feed names are constructed by combining components within six facets: (i) origin, including scientific name (genus, species, variety), common name (genus, species, variety) and chemical formula where appropriate; (ii) part fed to animals as affected by process(es); (iii) process(es) and treatment(s) to which the origin of part eaten was subject prior to being fed to the animal; (iv) stage of maturity and development (applicable to forages and animals); (v) cutting (primarily applicable to forages); and (vi) grade (official grades and guarantees, etc.). In addition, feeds are separated into eight classes: (i) dry forages and roughages; (ii) pasture, range plants or forages fed green; (iii) silages; (iv) energy feeds; (v) protein supplements; (vi) mineral supplements; (vii) vitamin supplements; and (viii) additives. Each class represents a special characteristic peculiar to a given group of feed products. A six-digit IFN is assigned to each feed and is used in the accompanying tables of feedstuffs composition. The first digit of this number denotes the class of feed. The remaining digits are assigned consecutively but never duplicated. The reference number is used in computer programs to identify the feed for use in calculating diets, for summarization of data, for printing feed composition tables and for retrieving online data on a specific feed.

Cereal Grains and By-products

The primary sources of energy in swine diets are cereal grains. Thus they are important constituents of pig diets. In addition to the whole grains, the processing of cereals for the human market yields by-products that are important as feed ingredients. Most of the cereals suitable for use in organic pig production belong to the grass family (*Poaceae*). Their seeds (grains) are high in carbohydrate and they are generally palatable and well-digested. Nutrient composition can be quite variable, depending on differences in crop variety, fertilizer practices and growing, harvesting and storage conditions. Variability may be higher in organic grains than in conventional grains because of the fertilizer practices in organic grain production, but the data are inadequate at present. Generally the crude protein content is slightly lower than in conventionally-grown cereals (Jacob, 2007; Blair, 2012; Kyntäjä *et al.*, 2014) and according to Grela and Semeniuk (2008) organic cereals also contain a higher content of crude fibre and a lower level of energy than conventionally-grown grains. The Grela and Semeniuk study suggested a slightly lower content of minerals in organic cereals, but the content appeared to be affected mainly by factors such as soil type, fertilization practice and plant species. Cereal by-products tend to be more variable than the grains and therefore their use in swine diets may have to be limited to achieve consistency of the formulations.

The fibre in grains is contained mainly in the hull (husk) and can be variable, depending on the growing and harvesting conditions. This can affect the starch content of the seed and, as a consequence, the energy value. The hull is quite resistant to digestion and also has a lowering effect on the digestibility of nutrients.

On a dry basis, the CP (crude protein) content ranges from about 100 to 160 g/kg and is often variable. The protein is low in important AA (lysine, methionine, threonine and tryptophan) in relation to the pig's requirement. Grains also tend to be low in vitamins and minerals. Therefore, cereal grain-based diets must be supplemented with other ingredients to meet AA and micronutrient requirements. Yellow maize is the only cereal grain to contain vitamin A, owing to the presence of provitamins (mainly β-carotene). All grains are deficient in vitamins D and K, but supplementation with vitamin K is not required unless normal intestinal synthesis is impaired in the animal. The ether extract (oil) in cereal grains is contained in the germ and varies from less than 20 g/kg (dry basis) in wheat to over 50 g/kg in oats. It is high in oleic and linoleic acids, which are unstable after the seed is ground. As a result, rancidity can develop quickly and result in reduced palatability of the feed or feed refusal.

The cereals in general are good sources of vitamin E and may supply the entire requirement for this vitamin, provided the grain is used quickly after processing to prevent the development of rancidity and off-flavour. The oil of wheat germ is one of the best known natural sources of vitamin E, but is unstable. Of the principal B vitamins, the cereals are good sources of thiamin but they are low in riboflavin. Maize, oats and rye are much lower in niacin than are barley and wheat. Maize is also low in pantothenic acid and all grains are deficient in vitamin B_{12}. All cereal grains, especially maize, are deficient in calcium. They contain much higher levels of phosphorus but much of the phosphorus is bound as phytate, which is largely unavailable to pigs. Also, phytate affects the availability of calcium and other minerals. Plant breeders are aware of the phytate issue and are developing new cultivars of cereals with reduced phytate content. A barley cultivar with 75% reduction in phytate phosphorus was introduced in Canada in 2006. Cereals generally supply enough magnesium, but insufficient levels of sodium and possibly potassium. None of the cereals contains high levels of trace minerals.

Thus feed grains meet part of the requirement for dietary nutrients. Other feed components are needed to balance the diet completely. Combining the grains and other ingredients into a final dietary mixture to meet the pig's nutritional needs requires information about the nutrient content of each feedstuff and its suitability as a feed ingredient.

Maize, wheat, oats, barley and sorghum are the principal cereals, the whole grains of which are used for feed. Generally, maize and wheat are highest in energy value for pigs. Sorghum, barley, oats and rye are lower in energy. Some rye is used in pig feeding. Although it is similar to wheat in composition, it is less palatable than other grains and may contain ergot, a toxic fungus. Triticale, a hybrid of rye and wheat, is also being used for pig feeding in some countries. There do not appear to be any GM varieties of wheat, sorghum, barley or oats being grown, unlike the situation with maize: in the USA, for instance, substantial quantities of GM maize varieties developed with insect and herbicide resistance are being grown. Such bioengineered varieties are obviously unsuitable for organic pig production.

Average composition values of commonly used feeds are presented in the tables at the end of this chapter and can to be used as a guide in formulating diets for swine. However, it is recommended that, where possible, chemical analysis of the grain or feed product is conducted prior to feeding, to determine more exactly its nutrient composition and quality. Analyses for moisture, protein (and possibly lysine) and kernel weight are generally adequate for grains.

Several by-products of grain milling and processing are valuable ingredients for pig diets. The grain seed consists of an outer hull or bran fraction covering the endosperm fraction, which consists mainly of starch and some protein. At the base of the seed is the germ which contains most of the fat (oil), fat-soluble vitamins and minerals. Processing of grains for the human market usually involves removal of the starch, leaving the other fractions as animal feed. The composition of these by-products varies according to the process used. Grain screenings (cleanings) are used in conventional animal feeding. These contain broken and damaged grains, weed seeds, dust, etc. and probably do not meet the quality standards for organic pig diets.

Barley and by-products

Barley (*Hordeum* spp.) is grown more widely throughout the world than any other cereal. It is grown in regions of North America, Europe and Australia that are less well adapted to maize, typically where the growing season is relatively short and climatic conditions cool and dry. It is the major feed grain grown in Canada, mainly in the prairies. Barley is also a good rotation crop with wheat, tends to be higher-yielding, matures earlier, and is more resistant to drought and salinity problems. Barley is classified as six-row or two-row, depending on the physical arrangement of kernels on the plant. Two-row varieties are adapted to drier climates and six-rowed cultivars to the wetter areas.

Traditionally the higher grades of barley have been used for malting and the lower grades for livestock feed. High-quality barley can be an excellent grain source for pig diets. It has been used for some time as the principal grain for pig feeding in the western areas of North America, the UK and many countries of Europe because of its better adaptation to climate and the firmer, leaner carcasses produced than with maize-based diets.

Fig. 4.1. Barley is an excellent cool-season grain crop for organic pig feeding.

NUTRITIONAL FEATURES Barley is considered a medium-energy grain, lower in DE than maize. It contains more fibre than maize and less than oats, but the proportion of hull to kernel is variable, resulting in variable DE value. The protein content is higher than in maize and can range from about 90 to 160 g/kg. According to Kyntäjä *et al*. (2014) barley grown organically in Europe has a CP content of 112 g/kg (DM basis), whereas the value normally reported by other researchers for conventionally-grown barley is around 125 g/kg. A large study in Poland found that the average CP value was 108.7 g/kg in organic barley compared with 112.8 in conventional barley (Grela and Semeniuk, 2008). The corresponding values for CF and ME were 42.1 and 39.3 g/kg, and 13.95 and 14.3 MJ/kg DM. The AA profile of barley protein is better than in maize and is closer to that of oats or wheat, and the bioavailability of EAA is high. Barley contains more phosphorus than other common cereal grains.

PIG DIETS Barley is more suitable in diets for sows and growing-finishing pigs than in diets for young pigs, because of its higher fibre content and lower DE value relative to maize. The lower DE value tends to result in poorer feed efficiency with barley-based diets. However, this effect is minimized by fine grinding (600–700 μm) and pelleting of the diet, several studies having shown improvements in growth rate of 8–12% by pelleting (Newman and McGuire, 1985; Graham *et al*., 1989). Barley with a kernel weight of 56.3 kg/hl or less has been shown to respond better to pelleting than higher-quality barleys (Harrold *et al*., 1989).

The preferred particle size for use in pig diets is approximately 700 μm with a relatively small range of particle size to promote uniform mixing (Goodband *et al*., 1997).

Lower-quality barley should be used in dry-sow diets. The increased fibre is beneficial in helping to produce gut-fill in these animals on a restricted feeding regimen and helps to develop gut capacity so that the animals are better able to consume the maximum amount of feed during lactation. In addition the diet can be fed in meal form during gestation, avoiding the expense of pelleting. Barley can be used in lactation diets, particularly during early lactation when fibre intake may be beneficial in avoiding constipation. If used later in lactation the diets should be supplemented with high-energy ingredients and the diet should preferably be pelleted. Barley-based diets are less popular than maize-based diets for growing-finishing pigs in hotter regions because of the higher fibre and resultant higher heat increment resulting from fermentation in the large intestine, which can lead to a decrease in feed intake and a reduction in growth rate.

Hull-less barley

NUTRITIONAL FEATURES Hull-less barley varieties have been developed in which the hull separates during threshing. These varieties contain more protein and less fibre than conventional barley, and theoretically should be superior in nutritive value to conventional barley.

PIG DIETS Several studies have failed to show improved growth performance over conventional barley in growing-finishing pigs, and attempts have been made to provide an explanation. Thacker (1999a) reported that the CP digestibility was 9.2% lower with hull-less barley diets than with conventional (hulled) barley diets. Thacker *et al.* (1988) compared hulled (Harrington) and hull-less (Scout) barley as a grain source for growing pigs and found no significant difference in daily gain (0.75 versus 0.74 kg) between the diets. However, feed efficiency with diets based on hull-less barley was significantly better than with hulled barley (3.13 versus 3.30). Carcass traits were not affected by diet. There was no significant difference in the digestibility of CP or energy between diets, although DM digestibility was slightly higher with the hull-less barley diet than with the hulled barley diet (80.6 versus 78.7%).

One possible explanation for the poorer feed efficiency with hull-less barley is a higher content of β-glucans in this grain. However, responses to additions of β-glucanases to diets based on regular barleys fed intact or after mechanical dehulling have not been consistent (Graham *et al.*, 1989). The gut microflora of pigs appears able to hydrolyse β-glucans. Heat processing of conventional or hull-less barley by micronization does not appear to improve utilization of the carbohydrate or protein fractions (Thacker, 1999a), although it increased the percentage of gelatinized starch in both hulled and hull-less barley diets. Diet viscosity also increased with micronization. The micronization process increased the digestibility of CP by 8.0% and GE by 4.4%. Digestibility of DM and energy was similar with both types of barley. Although micronization led to some improvements, it resulted in a significant reduction in feed intake. This led to a 14.3% reduction in the growth rate of pigs fed the micronized barley-based diets. Over the entire growth period (19–80 kg), pigs fed micronized diets gained weight 10.3% slower than pigs fed untreated barley. The slower growth appeared to be due, at least partially, to a 14.3% reduction in feed intake, which was attributed to an increase in diet viscosity.

These results suggest that hull-less barley can be used in organic pig diets as a substitute for conventional barley on the assumption that they are similar in nutritive value.

Brewer's dried grains

Brewer's dried grains (often referred to as spent grains) is the extracted dried residue of barley malt alone or in mixture with other cereal grain or grain products resulting from the manufacture of wort or beer. This by-product consists largely of structural carbohydrates (cellulose, hemicellulose) and the protein remaining after barley is malted and mashed to release sugars for brewing (Westendorf and Wohlt, 2002). Other grains may be added with the barley.

NUTRITIONAL FEATURES Because of the removal of sugars and starches, the spent grains are higher in CP and lower in energy than the original grain. The CP, oil and CF contents of brewer's grains are approximately twice as high as in the original grain. According to data from Westendorf and Wohlt (2002), CP ranges from 210 to 290 g/kg on a DM basis (US data). Some recent data cited by these authors indicate a higher average CP content, 290–330 g/kg (DM basis). They speculated that the increase might be due to improved varieties of barley, maize and rice being used for brewing, different brewing methods, or changes in the recovery or pooling of wastes generated during the brewing process.

Other by-products of the brewing process are malt sprouts, brewer's condensed solubles (produced from the mechanical dewatering of brewer's grains) and brewer's yeast. Most of the brewer's grains is marketed in the wet form as a dairy cattle feed (Westendorf and Wohlt, 2002). However, some dried product may be available economically as a feed ingredient for pig diets.

North American definitions of the main by-products of brewing that are suitable for pig feeding are as follows:

- *Brewer's dried grains* are the dried extracted residue of barley malt alone or in mixture with other cereal grains or grain products resulting from the manufacture of wort or beer and may contain pulverized dried spent hops in an amount not to exceed 3% evenly distributed: IFN 5-00-516 Barley brewer's grains dehydrated.
- *Malt sprouts* are obtained from malted barley by the removal of the rootlets and sprouts which may include some of the malt hulls, other parts of malt, and foreign material unavoidably present. The traded product must contain not less than 24% CP. The term malt sprouts, when applied to a corresponding portion of other malted cereals, must be in a qualified form: i.e. 'rye malt sprouts', 'wheat malt sprouts', etc. Malt sprouts are also known as malt culms in some countries: IFN 5-00-545 Barley malt sprouts dehydrated; IFN 5-04-048 Rye malt sprouts dehydrated; IFN 5-29-796 Wheat malt sprouts dehydrated.
- *Malt cleanings* are obtained from the cleaning of malted barley or from the re-cleaning of malt that does not meet the minimum CP standard of malt sprouts. They must be designated and sold according to the CP content: IFN 5-00-544 Barley malt cleanings dehydrated.
- *Brewer's wet grains* are the extracted residue resulting from the manufacture of wort from barley malt alone or in mixture with other cereal grains or grain products. The guaranteed analysis should include the maximum moisture content: IFN 5-00-517 Barley brewer's grains wet.
- *Brewer's condensed solubles* are obtained by condensing liquids resulting as by-products from manufacturing beer or wort. The traded product must contain not less than 20% total solids and 70% carbohydrates on a DM basis, and the guaranteed analysis must include maximum moisture content: IFN 5-12-239 Barley brewer's solubles condensed.
- *Brewer's dried yeast* is the dried, non-fermentative, non-extracted yeast of the botanical classification *Saccharomyces* resulting as a by-product from the brewing of beer and ale. The traded product must contain not less than 35% CP. It must be labelled according to its CP content: IFN 7-05-527 Yeast brewer's dehydrated.

PIG DIETS Brewer's grains are commonly fed to farm livestock. Most of the brewer's grains used in pig diets is in the dry form. According to Holden and Zimmerman (1991) dried brewer's grains can make up a substantial portion of gestation diets, but should not be used as a component of starter diets and should be used only as a minor ingredient in lactation or growing-finishing diets. Walhstrom and Libal (1976) successfully used brewer's dried grains up to 400 g/kg in the diet of gestating sows when the lysine level was maintained at 5 g/kg. There were no treatment differences in reproductive performance. Litter size and weight of individual piglets, litter weight at birth and weaning were not affected by treatment. Growing-finishing pigs have been fed diets containing dried brewer's grains up to 230 g/kg without affecting growth rate, but feed conversion efficiency suffered incrementally with increasing level of dried brewer's grains (Holden and Zimmerman, 1991).

Buckwheat (*Fagopyrum* spp.)

Buckwheat is a member of the Polygonaceae family and is most commonly grown for human consumption. The protein quality of buckwheat is considered to be the highest of the grains, being high in lysine. However, buckwheat is low in DE relative to other grains due to its high fibre and low oil contents. Another significant factor limiting the use of buckwheat in pig diets is the presence of an anti-nutritional factor, fagopyrin, which causes skin lesions and intense itching when pigs consuming buckwheat-based diets are exposed to sunlight. As a result, buckwheat is not recommended for inclusion in organic pig diets.

Maize (*Zea mays*)

This cereal is also known as corn or Indian corn in the Americas and is grown in several countries. It is the most important feed grain in the USA because of its palatability, high energy value and high yields of digestible nutrients per unit of land. Consequently it is used as a yardstick in comparing other feed grains for pig feeding. The plains of the USA provide some of the best growing conditions for maize, making it the world's top maize producer. Other major maize producers are China, Brazil, the EU, Mexico and Argentina.

NUTRITIONAL FEATURES Maize is high in carbohydrate, most of which is highly digestible starch, and low in fibre. It has relatively high oil content; thus maize has a high DE value. Other grains, except wheat, have a lower DE value than maize. Maize oil has a high proportion of unsaturated fatty acids and is an excellent source of linoleic acid. The use of yellow maize grain should be restricted in pig diets if it results in carcass fat that is too soft or too yellow for the market in question. White maize can be used to avoid the fat coloration. Yellow and white maize are comparable in energy, protein and minerals, but yellow maize has more carotene than white maize. Yellow maize also contains the pigment cryptoxanthin, which can be converted into vitamin A in the animal's body.

The protein concentration in conventional maize is normally about 85 g/kg (air-dry basis) but Jacob (2007) reported a value of 72.9 in organic maize versus 75.0 in conventional maize, suggesting that the CP content of maize should be checked before being formulated into pig diets. The protein is not well balanced in AA content, with lysine, threonine, isoleucine and tryptophan being limiting. Varieties such as Opaque-2 and Floury-2 have improved AA profiles but do not appear to yield as well as conventional varieties. As a result they are not grown extensively. Producers wishing to use such varieties should check their acceptability with the organic certifying agency.

Maize is very low in calcium (about 0.2 g/kg). It contains a higher level of phosphorus (2.5–3.0 g/kg) but much of the phosphorus is bound in phytate form that is poorly available to pigs. As a result a high proportion of the phosphorus passes through the gut and is excreted in the manure. The diet may be supplemented with phytase enzyme to improve phosphorus utilization. Another approach would be to use one of the newer low-phytic-acid maize varieties that have about 35% of their phosphorus bound in phytate acid compared with 70% for conventional maize. These varieties allow the phosphorus to be utilized more effectively by the pig and with less excreted in the manure. As with other improved varieties of maize, producers wishing to use such varieties should check their acceptability with the organic certifying agency. Maize is low in potassium and sodium, as well as in trace minerals.

Maize is low in vitamins but contains useful amounts of biotin and carotenoids. Niacin is present in a bound form and together with a low level of tryptophan, a niacin precursor, leads to this vitamin being particularly limiting in maize-based diets unless supplemented.

The quality of maize is excellent when harvested and stored under appropriate conditions, including proper drying to 100–120 g moisture/kg. Fungal toxins (zearalenone, aflatoxin and ochratoxin) can develop in grain that is harvested damp or allowed to become damp during storage. These toxins can cause adverse effects in pigs, especially on sow productivity. Varieties differ markedly in storage characteristics due to husk coating and endosperm type.

PIG DIETS Maize is suitable for feeding to all classes of pig. It should be ground medium to medium-fine for use in mash diets and fine for inclusion in pelleted diets. The grain should be mixed into feed immediately after grinding since it is likely to become rancid during storage.

Hominy feed

Grain-processing plants offer by-products that are suitable for livestock use, if acceptable by organic certification agencies. In producing ground maize for the human market the hull and germ are removed, leaving hominy feed, consisting of bran, germ and some endosperm. It resembles the original grain in composition, but has higher contents of fibre, protein and oil.

Hominy feed is an excellent feed for pigs, similar to whole maize in DE value because of the higher oil content. One of the benefits of using maize by-products such as this is that the grain used is of very high quality since the main product is intended for the human market. This helps to ensure that the maize is free from mycotoxin contamination and insect and rodent infestation.

Maize gluten feed

Maize gluten feed is a maize by-product that is available in some regions as a wet or dry product. The dry product is traded internationally. Because its method of production can vary, it tends to be of variable feed value depending on the exact process in use. Therefore it should be purchased on the basis of a guaranteed analysis. Maize gluten feed (also called corn gluten feed) is a by-product of starch production. In the North American process the maize is soaked ('steeped') in water and sulphur dioxide, for 30–35 h at 35–47°C, to soften it for the initial milling step. During this process, some nutrients dissolve in the water (steep liquor). When the steeping is complete, this liquor is drawn off and concentrated to produce 'solubles'. During the wet-milling process, the germ is separated from the kernel and may be further processed to remove the oil. In a secondary wet-milling process the remaining portion of the kernel is separated into the hull (bran), gluten and starch fractions. The bran fraction is then mixed with steep liquor and the germ fraction and marketed as maize gluten feed, wet or dehydrated. The gluten fraction may be marketed as maize gluten meal or may be added back to the maize gluten feed. The dried maize gluten feed is made into pellets to facilitate handling. It analyses typically at 210 g protein, 25 g fat and 80 g CF on a per kg basis. Wet maize gluten feed (450 g/kg DM) is similarly combined but not dried. It is a perishable product that has to be used within 6–10 days and must be stored in an anaerobic environment.

Maize gluten meal

Maize gluten meal is not a very suitable feed for pigs since it is of relatively low palatability and has an imbalanced AA profile. It may no longer be available or economic for feed use as it is being used extensively as a natural weedkiller in horticulture.

Distiller's dried grains

This maize by-product is commonly used in pig feeding. It is derived from ethanol production (as a fuel source or as liquor). This North American by-product is exported to several regions, including Europe. In the production process dry-milling is used, followed by cooking and fermentation of the starch fraction with yeast, to produce ethanol. Removal of the starch leaves the nutrients in the remaining residue at about three times the content in the original grain. Evaporation of the remaining liquid produces solubles which are usually added back to the residue to produce distiller's grains plus solubles. Usually this product is dehydrated and marketed as distiller's dried grains plus solubles (DDGS). One of the benefits of this product is the contribution of nutrients provided by yeast.

DDGS typically analyses at 270 g protein, 110 g fat and 90 g CF on a per kg basis. Cromwell *et al.* (1993) reported considerable variability in the nutritional value of DDGS, depending on source. The reported range was 234–287 g CP/kg, 29–128 g fat/kg, 288–403 g NDF/kg, 103–181 g ADF/kg and 34–73 g ash/kg. Lysine concentration ranged from 4.3 to 8.9 g/kg. Rate and efficiency of gain in growing pigs were correlated with colour of the DDGS and its concentrations of CP, lysine, sulphur-containing AA and ADF. These authors concluded that a light-coloured DDGS, free from burnt or smoky odour, was more likely to have good nutritional properties for pigs. The nutritional value of DDGS from fuel alcohol production appeared to be similar to that from beverage alcohol production. In more recent work, Shurson *et al.* (2004) reported that some of the DDSG now being produced in the USA is higher in DE content, apparent digestible AA and available phosphorus than in the published literature. They found that up to 10% could be included satisfactorily in the diet of growing pigs. Higher levels resulted in soft fat in the carcass, due to its oil content. Up to 500 g/kg could be included in diets for dry sows and up to 200 g/kg in lactation diets.

Oats (*Avena sativa*)

Oats are grown in cooler, wetter regions. Today the world's leading oats producers are Russia, the EU, Canada, the USA and Australia.

NUTRITIONAL FEATURES The chemical composition can vary widely, depending on variety, climate and fertilizer practices. Threshed oats remain enclosed in the hulls, leaving the chaffs (glumes) on the straw. Oats are higher in hull, CF and ash contents and are lower in starch than maize, grain sorghum or wheat. The proportion of hulls can range from 45 to 200 g/kg. They thus have a much lower energy value than other main cereals. The nutritional value is inversely related to the hull content, which can be approximated from the thousand-kernel weight. Oats vary in protein content from about 110 to 170 g/kg, with an AA profile similar to wheat, being limiting in lysine, methionine and threonine. The protein content is affected mainly by the proportion of hull, since it is present almost entirely in the kernel. Oats have higher oil content than maize, but this does not compensate for the high fibre content. A large study in Poland found that the average CP value was 113.1 g/kg in organic oats compared with 115.7 in conventional oats (Grela and Semeniuk, 2008). The corresponding values for CF and ME were 147.2 and 134.5 g/kg, and 12.1 and 12.6 MJ/kg DM. Jacob (2007) reported a higher content of CP in organic oats, 123.1 versus 110 g/kg in conventional oats.

PIG DIETS Oats are best used in sow gestation diets since they provide a good source of bulk due to the high fibre content. They are less suitable for lactating sows and growing-finishing pigs, where higher-energy diets are required. It can be useful to include some oats in the diet of growing-finishing pigs to prevent against gastric ulcers. Newer varieties of oats with lower hull content may be more suitable for lactation and growing-finishing diets.

Fine grinding of oats and pelleting of the diet are important for optimal utilization by growing-finishing pigs and to prevent sorting of mash diets in self-feeders. Coarse grinding of oats can be used with gestation diets. Inclusion of a low level of oats in the diet of weaned pigs may help to prevent problems of diarrhoea. The inclusion of oats may have to be avoided during hot weather because of a higher heat increment which can result in reduced feed intake and growth rate.

Naked (hull-less) oats

Naked oat varieties have been developed. These varieties lose their hull during harvesting and consequently are much lower in fibre than hulled oats. Naked oats have higher protein and fat contents than conventional oats, resulting in a DE value similar to that of maize. The balance of AA is also better than in conventional oats, with only lysine and methionine being limiting. They have been reported to give good growth performance when used as the sole grain in diets for growing-finishing pigs, with little supplemental protein required (Morris and Burrows, 1986). Although naked oats have been grown successfully in Canada and northern regions of the USA, the yields are sometimes low.

Oat by-products

Oats are commonly processed mechanically to remove the hull from the kernel. The result is oat groats. After rolling, the product is known as rolled oat groats. This is a highly palatable, high-energy (3690 kcal DE/kg) feedstuff that is digested well by pigs. The protein content is around 160 g/kg. However, this product is too expensive for general use in pig diets and is used mainly in creep-feed and pig starter diets.

Rice (*Oryza sativa*)

As shown in Table 4.1, rice is not included in the list of permitted ingredients, therefore its acceptability should be checked with the local certifying agency.

The polished white rice that is an important staple food for a large section of the human population is obtained by milling paddy rice. It is first dehulled to yield the following fractions (approximate proportions in parentheses): brown rice (80%) and hulls (20%). The brown rice is then milled to yield rice bran (10%), white rice (60%) and polishings plus broken rice (10%). The main by-product – rice bran – is a mixture of hulls, germ and bran that is suitable for pig feeding. The polishings and broken grains are usually added to the bran. The percentage of by-products depends on milling rate, type of rice and other factors.

Rough rice (paddy or padi rice) can be used in pig diets but is generally not available. Rice after processing that does not meet the quality standards for humans is a good feed ingredient for pig diets, provided it is not moulded and contaminated with toxic fungi.

Rice by-products

Rice bran is the most important rice by-product. It is suitable as a grain substitute, equivalent to wheat in feeding value if of good quality. It is a good source of water-soluble vitamins and is palatable to pigs when used fresh. Up to 400g/kg rice bran has been used successfully in diets for growing pigs in several countries, with rice bran replacing part of the grain component (Farrell and Hutton, 1990). One of the problems with rice bran is the high oil content (140–180 g/kg), which is highly unsaturated and unstable. At high ambient temperature and in the presence of moisture the oil breaks down into glycerol and free fatty acids, due to the presence of a lipolytic enzyme that becomes active when the bran is separated from the rice. The result is an unpleasant taste and odour and reduced palatability of the product. Peroxidation of the oil was attributed to the incidence of vitamin E-responsive conditions reported in Australia (Farrell and Hutton, 1990). A ratio of vitamin E to linoleic acid of 0.6 mg/g has been recommended as a precautionary measure (Farrell and Hutton, 1990). Stabilization of the oil in other ways (e.g. by use of an antioxidant) should also be considered, if acceptable by the certifying agency. Another aspect of the oil is that its high content of unsaturated fatty acids can lead to soft backfat in the carcass. This restricts the amount of rice bran that can be included in the diet of growing-finishing pigs. For growing pigs, rice bran should not exceed 300–400 g/kg total diet and in the final weeks of finishing lower levels must be used. Farrell and Hutton (1990) recommended a dietary content of less than 16 g linoleic acid/kg to avoid a soft backfat problem.

The oil can be extracted from the bran to avoid the problems noted above. De-oiled rice bran can be used at higher levels than regular rice bran. Apart from extraction of the oil the rancidity process can be delayed by heating or drying immediately after milling to reduce the moisture content to below 4%. Heating to 100°C for 4 or 5 min with live steam is sufficient to retard the increase in free fatty acids. The rice bran can also be heated dry if spread out on trays at 200°C for 10 min.

Some producers in Asia feed rice bran, with or without a supplement, as the complete feed for growing-finishing pigs. It is more suitable for sow gestation diets than for other pig diets due to its bulk and laxative effect.

Rye (*Secale cereale*)

Rye is used less commonly than other cereals because it is often contaminated with a fungal toxin. Therefore its acceptability should be checked with the local certifying agency.

Rye has an energy value intermediate to that of wheat and barley, and the protein content is similar to that of barley and oats. A large study in Poland found that the average CP value was 82.7 g/kg in organic rye compared with 86.8 in conventional rye (Grela and Semeniuk, 2008). The corresponding values for CF and ME were 21.3 and 21.4 g/kg, and 14.3 and 15.2 MJ/kg DM.

Although the AA balance is similar to that of barley and wheat, its AA digestibility is 5–10% lower. Rye may also contain several toxic anti-nutritional factors that reduce its nutritional value for the pig, notably ergot, which is a fungus that reduces pig health and performance. There is no limit on the amount of rye that can be fed to gestating sows, although an upper limit of 500 g/kg in grower-finisher and 400 g/kg in lactation diets is suggested.

Sorghum (Sorghum vulgare)

Sorghum, commonly called grain sorghum or milo, is the third most important cereal crop grown in the USA and the fifth most important cereal crop grown in the world. Much of it is used in the human market. As a continent, Africa is the largest producer of sorghum. Other leading producers include India, Mexico, Australia and Argentina. Sorghum is one of the most drought-tolerant cereal crops and is more suited than maize to harsh weather conditions such as high temperatures and less consistent rainfall.

NUTRITIONAL FEATURES Grain sorghum is generally higher in CP than maize and is similar in DE content. However, one disadvantage of grain sorghum is that it can be more variable in composition because of growing conditions. CP content usually averages around 89 g/kg, but can vary from 70 to 130 g/kg. Therefore, a protein analysis prior to formulation of diets is recommended.

PIG DIETS Grain sorghum can be used extensively as a cereal grain in pig diets, as a replacement for maize. The hybrid yellow-endosperm varieties are more palatable to pigs than the darker brown sorghums, which possess a higher tannin content that deters wild birds from damaging the crop. Lysine is the most limiting AA in the protein, followed by tryptophan and threonine. Research results from South Africa show that low-tannin grain sorghum cultivars can be used successfully as the main or only grain source in well-balanced pig growth diets (Kemm and Brand, 1996). Proper grinding of grain sorghum is important because of the hard seed coat. Whole kernels are not completely masticated by pigs and pass through the intestinal tract undigested. Mills should be set to break all of the kernels without producing a fine, dusty feed. Grinding is usually followed by pelleting of the diet.

A high proportion of the sorghum grown in the USA is used for ethanol production, yielding by-products such as distiller's dried grains with solubles (sorghum-DDGS) for animal feeding.

Spelt (*Triticum aestivum* var. *spelta*)

Spelt is a subspecies of wheat grown widely in Central Europe. It has been introduced to other countries partly for the human market because of its reputation as being low in gliadin, the gluten fraction implicated in coeliac disease.

This crop appears to be generally more winter-hardy than soft red winter wheat, but less winter-hardy than hard red winter wheat. The yield is generally lower than that of wheat but equal to wheat when the growing conditions are less than ideal.

NUTRITIONAL FEATURES Research studies suggest that this grain is similar to wheat in nutritive value for pigs, but with a higher CP content (Ranhotra *et al.*, 1996a). For instance, Ranhotra *et al.* (1996b) reported an average CP value of 166 g/kg in a range of spelt varieties in the USA versus 134 g/kg in a range of wheat varieties. The average lysine content was 29.3 g/kg protein in spelt versus 32.1 g/kg protein in wheat. The estimated energy value of the two grains was similar. The nutrient profile of both grains was found to be greatly influenced by cultivar and location. All spelt and wheat samples tested contained gluten. A large study in Poland found that the average CP value was similar at 114.1 g/kg in organic and conventional spelt (Grela and Semeniuk, 2008). The corresponding values for CF and ME were 31.2 and 30.3 g/kg, and 14.8 and 14.9 MJ/kg DM.

PIG DIETS Research on spelt grown in the Slovak Republic and Sweden (Chrenková *et al.*, 2000) confirmed the above findings on spelt composition and reported no significant differences in grain type on the basis of growth in rats. CP digestibility was higher with spelt than with wheat (0.85 versus 0.81). The quality of the protein in spelt wheat was higher than in winter wheat Samanta, as reflected by higher net protein utilization and utilizable protein values.

Based on the limited information available it appears that spelt can be utilized in pig diets as a replacement for wheat. Laboratory analysis should be conducted to confirm the nutritive content. Expansion of this crop is likely in Europe because of the current shortage of high-protein organic feedstuffs.

Triticale (*Triticale hexaploide, Triticale tetraploide*)

Triticale is a hybrid of wheat (*Triticum*) and rye (*Secale*) developed with the aim of combining the grain quality, productivity and disease resistance of wheat with the vigour, hardiness and high lysine content of rye. The first crossing of wheat and rye was made in Scotland in 1875 (Wilson, 1876) although the name 'triticale' did not appear in the scientific literature until later. Triticale can be synthesized by crossing rye with either tetraploid (durum) wheat or hexaploid (bread) wheat. It is grown mainly in Poland, China, Russia, Germany, Australia and France, although some is grown in North and South America. It is reported to grow well in regions not suitable for maize or wheat. Globally, triticale is used primarily for livestock feed. Current grain yields in Canada (Briggs, 2002) are competitive with the highest-yielding wheat varieties, and may exceed those of barley. Also, the high quality of the protein has been maintained in the newer varieties. Both spring and winter types are now available (including a semi-awnless winter variety) and have provided a new crop option for breaking disease cycles in cereal cropping systems. According to Briggs (2002) the greatest potential for its use as a grain feedstuff is in pig operations that grow at least part of their own feed grain supply, using lands that are heavily manured from the feed operation. Triticale production in such conditions is generally more productive and sustainable than barley or other cereals for feed grain. Its greater disease resistance compared with wheat and barley is another advantage. Thus triticale will be of particular interest to organic pig producers.

NUTRITIONAL FEATURES The use of many varieties and crosses to improve yield and grain quality in triticale as well as adaptation to local conditions has resulted in a variation in nutrient composition. The protein content of newer varieties is in the range 95–132 g/kg, similar to that of wheat (Briggs, 2002; Stacey *et al.*, 2003). Typical lysine contents (g/kg) reported by Hede (2001) from work in Mexico and Ecuador are triticale 50.4, barley 29.4, wheat 43.0, and maize 22.7. DE and ME values have been reported as generally equal to or higher than in wheat (Evans, 1998; Hede, 2001). It is known that the newly developed Canadian varieties (× Triticosecale Wittmack L.) possess more of the characteristics of the wheat parent than the rye parent, resulting in higher DE content and improved palatability and nutritional value. In addition they are low in anti-nutritive factors such as ergot which have been found in the older varieties. A large study in Poland found that the average CP value was 116.9 g/kg in organic triticale compared with 121.2 in conventional triticale (Grela and Semeniuk, 2008). The corresponding values for CF and ME were 26.4 and 24.6 g/kg, and 14.9 and 15.3 MJ/kg DM.

PIG DIETS Radecki and Miller (1990) reviewed the use of triticale in pig diets and concluded that triticale could replace maize in the diet of growing pigs provided the content of digestible lysine was maintained. They suggested an upper limit of 250 g triticale/kg in breeder diets. Trials at the University of Alberta Swine Research Farm with the variety Pronghorn included in diets to replace wheat, maize or hull-less barley showed that pigs on all three diets had a similar voluntary feed intake and a similar growth performance (Jaikaran *et al.*, 2000a,b). Animals fed maize- or triticale/hull-less barley-based diets produced carcasses with significantly higher backfat than with barley- or triticale-based diets and with about 1% lower estimated lean yield. Van Barneveld (1999a) found that when pig diets were formulated to supply equal levels of digestible AA and DE, the performance of growing pigs fed triticale was equal or superior to performance with wheat-based diets.

Wheat (*Triticum aestivum*)

Wheat grain consists of the whole seed of the wheat plant. This cereal is widely cultivated in temperate countries and in cooler parts of tropical countries. Several types of wheat are grown in North America. These include soft white winter, hard red winter, hard red spring and soft red winter wheat. Soft red winter wheat is comparable in feeding value to hard red winter wheat for finishing pigs. The types grown in Europe and Australia include white cultivars. Wheat is commonly used for feeding to pigs when it is surplus to human requirements or is considered not suitable for the human feed market. Otherwise it may be too expensive for pig feeding. However, some wheat is grown for feed purposes. By-products of the flour-milling industry also are very desirable ingredients for pig diets.

During threshing, the husk – unlike that of barley and oats – detaches from the grain, leaving a less fibrous product. As a result wheat is equal to maize in DE value but contains more CP, lysine and tryptophan. Thus it can be used as a replacement for maize as a high-energy ingredient and it requires less protein supplementation than maize.

Wheat is very palatable if not ground too finely and can be utilized efficiently by all classes of pig. Good results are obtained when wheat is coarsely ground (hammer mill screen size of 4.5–6.4 mm). Finely ground wheat is not desirable because it is too powdery, causing the animals discomfort in eating unless the diet is pelleted. In addition, finely ground wheat readily absorbs moisture from the air and saliva in the feeder, which can result in feed spoilage and reduced feed intake. Also, feed containing finely ground wheat can bridge and not flow well in feeding equipment. One benefit of wheat as a feed ingredient is that it improves pellet quality due to its gluten content, so that the use of a pellet binder may be unnecessary.

NUTRITIONAL FEATURES One concern about wheat is that DE and CP contents are more variable than in other cereal grains such as maize, sorghum and barley (Zijlstra *et al.*, 2001). These researchers at the Prairie Swine Centre in Canada analysed a large range of Canadian wheat samples and reported that CP ranged from 122 to 174 g/kg, NDF from 72 to 91 g/kg and soluble non-starch polysaccharides (NSP) from 90 to 115 g/kg. The CF content was low overall and showed little variation. Kernel density was high (77–84 kg/hl) overall. The variation found in composition and nutritive value was related to the different wheat classes and cultivars grown for human consumption, and to growing conditions and fertilizer practices. The results indicated a variation in DE of 20% and in CP content of 50%, although the range in CP in feed wheat is usually about 13–15%. Therefore periodic testing of batches of wheat for nutrient content is necessary.

A large study in Poland found that the average CP value was 118.7 g/kg in organic wheat compared with 124.2 in conventional wheat (Grela and Semeniuk, 2008).

The corresponding values for CF and ME were 29.9 and 26.7 g/kg, and 15.1 and 15.6 MJ/kg DM. Jacob (2007) reported that the CP content of organic wheat was 130.8 versus 135.0 g/kg in conventional wheat.

PIG DIETS The study referred to above (Zijlstra *et al.*, 2001) was extended to a growth performance study with weaned pigs weighing 12 kg. The wheat samples were included at 650 g/kg in diets of similar nutrient content and supplemented with soybean meal, canola oil and fishmeal. Slight reductions in feed intake or growth rate were reported with some wheat samples, but were limited to the first two weeks of feeding and were not present after 3 weeks of feeding. Wheat type did not appear to affect processing of the diets. This study confirmed other findings that a wide range of wheat types can be utilized efficiently in pig diets, provided the diets have been formulated appropriately.

Milling by-products

The main product of wheat milling is flour. Several by-products are available for animal feeding and are used extensively in pig diets because of their valuable properties as feed ingredients. Their use in this way minimizes the amount of whole grain that has to be used in pig diets. These by-products are usually classified according to their CP and CF contents and are traded under a variety of names that are often confusing, such as pollards, offals, shorts, wheatfeed and midds.

After cleaning (screening), sifting and separating, wheat is passed through corrugated rollers which crush and shear the kernels, separating the bran and germ from the endosperm. Clean endosperm is then sifted and ground to flour for human consumption. The mill may further separate the remaining product into middlings, bran, germ and mill run. Some bran and germ are used for human consumption as well as animal diets. Mill run includes cleanings (screenings) and all leftover fines and is often used for cattle feeding. In general the by-products with lower levels of CF are of higher nutritive value for pig diets.

AAFCO (2005) has defined the flour and wheat by-products for animal feeding in the USA as follows:

WHEAT FLOUR Wheat flour is defined as consisting principally of wheat flour together with fine particles of wheat bran, wheat germ, and the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain no more than 15 g CF/kg: IFN 4-05-199 Wheat flour less than 15 g fibre per kg.

WHEAT BRAN Wheat bran is the coarse outer covering of the wheat kernel as separated from cleaned and scoured wheat in the usual process of commercial milling: IFN 4-05-190 Wheat bran. Sometimes screenings are ground and added to the bran. Generally wheat bran has a CP level of 140–170 g/kg, crude fat (oil) content of 30–45 g/kg and CF content of 105–120 g/kg. Therefore, while wheat bran may have a CP level as high or higher than the original grain, the higher fibre level results in this product being low in energy. Consequently wheat bran is low in DE and has limited application in pig diets other than in sow gestation diets.

WHEAT GERM MEAL Wheat germ meal consists chiefly of wheat germ together with some bran and middlings or shorts. It must contain not less than 250 g CP and 70 g crude fat per kg: IFN 5-05-218 Wheat germ ground.

A wide variety of wheat germ grades is produced, depending on region, type of grain processed, and the presence of screenings and other wheat by-products. Generally wheat germ meal has a CP level of 250–300 g/kg; crude fat (oil) content of 70–120 g/kg and CF content of 30–60 g/kg. As with other feedstuffs containing a high level of plant oil, a problem that may result on storage is rancidity due to peroxidation of the fat.

A de-fatted product is also marketed. De-fatted wheat germ meal is obtained after the removal of part of the oil or fat from wheat germ meal and must contain not less than 300 g CP/kg: IFN 5-05-217 Wheat germ meal mechanical extracted.

The number of wheat germ meals available for pig feeding will usually be very limited due to availability and cost, since there are competing markets for these by-products.

WHEAT RED DOG Wheat red dog consists of the offal from the 'tail of the mill' together with some fine particles of wheat bran, wheat germ and wheat flour. This product must he obtained in the usual process of commercial milling and must contain no more than 40 g CF/kg: IFN 4-05-203 Wheat flour by-product less than 40 g fibre per kg.

Wheat red dog is a very fine, floury, light-coloured feed ingredient. The colour may range from creamy white to light brown or light red, depending on the type of wheat being milled. Wheat red dog can be used in pellets as a pellet binder, as well as source of protein, carbohydrate, minerals and vitamins. The average composition is CP 155–175 g/kg, crude fat 35–45 g/kg and CF 28–40 g/kg.

WHEAT MILL RUN Wheat mill run consists of coarse wheat bran, fine particles of wheat bran, wheat shorts, wheat germ, wheat flour, and the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain no more than 95 g CF/kg: IFN 4-05-206 Wheat mill run less than 95 g per kg crude fibre.

Wheat mill run usually contains some grain screenings. This by-product may not be available in areas that separate the by-products into bran, middlings and red dog. Wheat mill run generally has a CP level of 140–170 g/kg, crude fat content of 30–40 g/kg and CF content of 85–95 g/kg.

WHEAT MIDDLINGS Wheat middlings consists of fine particles of wheat bran, wheat shorts, wheat germ, wheat flour, and some of the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain no more than 95 g CF/kg: IFN 4-05-205 Wheat flour by-product less than 95 g per kg fibre.

The name 'middlings' derives from the fact that this by-product is somewhere in the middle between flour on one hand and bran on the other. This by-product is known as pollards in Europe and Australia. The composition and quality of middlings vary greatly due to the proportions of fractions included, also the amount of screenings added and the fineness of grind. A cooperative research study was conducted by members of the US Regional Committee on Swine Nutrition to assess the variability in nutrient composition of 14 sources of wheat middlings from 13 states mostly in the Midwest (Cromwell *et al.*, 2000). The bulk density of the middlings ranged from 289 to 365 g/l. The middlings averaged (g/kg): 896 DM, 162 CP, 1.2 calcium, 9.7 phosphorus, 369 NDF, 6.6 lysine, 1.9 tryptophan, 5.4 threonine, 2.5 methionine, 3.4 cystine, 5.0 isoleucine, 7.3 valine; and (mg/kg) 0.53 selenium. The variation in nutrient composition was especially high for calcium (0.8–3.0 g/kg) and selenium (0.05–1.07 mg/kg). 'Heavy' middlings (high bulk density, ≥ 335 g/l) had a greater proportion of flour attached to the bran, and were lower in CP, lysine, phosphorus and NDF than 'light' middlings (≤ 310 g/l). Other studies have shown that 'heavy' were superior in nutritional value to 'light' middlings for growing-finishing swine (Cromwell *et al.*, 1992).

Wheat middlings are used commonly in pig diets, as a partial replacement for grain and protein supplement in diets for growing-finishing pigs and sows. Responses to the inclusion of middlings in grower-finisher diets appear to be somewhat variable (Pond and Maner, 1984), related probably to variation in composition of the product. In conventional feed manufacturing this by-product is regarded as a combination of bran and shorts and tends to be intermediate between the two in composition. It also may contain some wheat screenings (weed seeds or other foreign matter that is removed prior to milling). It is commonly included in commercial feeds as a source of nutrients and because of its beneficial influence on pellet quality. When middlings (or whole wheat) are included in pelleted feeds, the pellets are more cohesive and there is less breakage and fewer fines. The feed manufacturing industry prefers middlings with a high bulk density over middlings with a low bulk density since they produce diets of higher nutritive quality.

WHEAT SHORTS Wheat shorts consist of fine particles of wheat bran, wheat germ, wheat flour, and the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain no more than 70 g CF/kg: IFN 4-05-201 Wheat flour by-product less than 70 g per kg fibre. (Note: the Canadian feed regulations have the IFN for middlings and shorts reversed.)

As with middlings, the responses to the inclusion of wheat shorts in grower-finisher diets appear to be somewhat variable (Pond and Maner, 1984), related probably to variation in composition of the product. Shorts can be used to supply all of the energy and protein in diets for gestating sows (Pond and Maner, 1984).

Oilseeds, Their Products and By-products

The major protein sources used in animal production are oilseed meals. Their use in pig diets was reviewed by Chiba (2001). Soybeans, groundnuts, canola and sunflowers are grown primarily for their seeds, which produce oils for human consumption and industrial uses. Cottonseed is a by-product of cotton production, and its oil is widely used for food and other purposes. In the past linseed (flax) was grown to provide fibre for linen cloth production. The invention of the cotton gin made cotton more available for clothing materials and the demand for linen cloth decreased. Production of linseed is now directed mainly to industrial oil production. The soybean is clearly the predominant oilseed produced in the world.

Moderate heating is generally required to inactivate anti-nutritional factors present in oilseed meals. Overheating needs to be avoided since it can result in a reduction in the amount of digestible or available lysine. Other AA such as arginine, histidine and tryptophan are usually affected to a lower extent. The potential problems of overheating are usually well recognized by oilseed processors. Only those meals resulting from mechanical extraction of the oil from the seed are acceptable for organic diets.

As a group, the oilseed meals are high in CP content except safflower meal with hulls. The CP content of conventional meals is usually standardized before marketing by admixture with hull or other materials. Most oilseed meals are low in lysine, except soybean meal. The extent of dehulling affects the protein and fibre contents, whereas the efficiency of oil extraction influences the oil content and the energy content of the meal. Meals from seed that has been oil-extracted mechanically contain more oil than conventional hexane-extracted meals, and thus have a higher energy value for pigs. Oilseed meals are generally low in calcium and high in phosphorus, although a high proportion of the phosphorus is present as phytate. The biological availability of minerals in plant sources such as oilseeds is generally low, and this is especially true for phosphorus because of the high phytate content.

Most of the oilseed crops now being grown world-wide are from GM cultivars, therefore caution must be exercised to ensure the use of non-GM crops for organic pig production.

Canola (*Brassica* spp.)

Canola (rapeseed) is a crop belonging to the mustard family, grown for its seed. The leading countries in rapeseed production are China, Canada, India and several countries in the EU. Commercial varieties of canola have been developed from two species: *Brassica napus* (Argentine type) and *Brassica campestris* (Polish type). Rapeseed has been important in Europe for a long time as a source of feed and oil for fuel. Production of this crop became popular in North America during World War II as a source of industrial oil, the crushed seed being used as animal feed. The name 'canola' was registered in 1979 in Canada to describe 'double-low' varieties of rapeseed, i.e. the extracted oil containing less than 20 g erucic acid per kg and the air-dry meal less than 30 mmol glucosinolates (any mixture of 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3-butenyl glucosinolate or 2-hydroxy-4-pentenyl glucosinolate) per g of air-dry material. In addition to the above standards for conventional canola, the meal is required to have a minimum of 350 g CP/kg and a maximum of 120 g CF/kg.

The designation is licensed for use in at least 22 countries. Erucic acid is a fatty acid that has toxic properties and has been related to heart disease in humans. Glucosinolates give rise to breakdown products that are toxic to animals. These characteristics make rapeseed products unsuitable as animal feedstuffs, but canola, like soybeans, contains both high oil content and high protein content and is an excellent feedstuff for pigs. Canola ranks fifth in world production of oilseed crops, after soybeans, sunflowers, groundnuts and cottonseed. It is the primary oilseed crop produced in Canada.

This crop is widely adapted but appears to grow best in temperate climates, being prone to heat stress in very hot weather. As a result, canola is often a good alternative oilseed crop to soybeans in regions not suited for growing soybeans. Some of the canola being grown is from GM-derived seed; therefore caution must be exercised to ensure the use of non-GM canola for organic pig production.

Canola seed that meets organic standards can be further processed into oil and a high-protein meal, so that the oil and meal are acceptable to the organic industry. In the commercial process in North America, canola seed is purchased by processors on the basis of grading standards set by the Canadian Grain Commission or the National Institute of Oilseed Processors. Several criteria are used to grade canola seed, including the requirement that the seed must meet the canola standard with respect to erucic acid and glucosinolate levels.

NUTRITIONAL FEATURES Per kg, canola seed contains about 400 g EE, 230 g CP and 70 g CF. A large study in Poland found that the average EE content in organic canola (rapeseed) was 403.2 g/kg compared with 411.5 in conventional canola (Grela and Semeniuk, 2008). The corresponding values for CP, CF and ME were 214.5 and 219.2, 71.3 and 66.9 g/kg, and 17.2 and 18.0 MJ/kg, respectively.

The oil is high in polyunsaturated fatty acids (PUFA; oleic, linoleic and linolenic), which makes it valuable for the human food market. It can also be used in animal feed. The oil is, however, highly unstable due to its PUFA content and, like soybean oil, can result in soft carcass fat unless restricted. For organic feed use the extraction has to be done by mechanical methods such as crushing (expeller processing), avoiding the use of solvent used in conventional processing. Two features of expeller processing are important. The amount of residual oil in the meal varies with the efficiency of the crushing process, resulting in a product with a more variable DE content than the commercial, solvent-extracted product. Also, the degree of heating generated by crushing may be insufficient to inactivate myrosinase in the seed. Therefore more frequent analysis of expeller canola meal for oil and protein contents is recommended and more conservative limits should be placed on the levels of expeller canola meal used in pig diets.

The extruded meal is a high-quality, high-protein feed ingredient. Canola meal from *B. campestris* contains about 350 g CP/kg, whereas the meal from *B. napus* contains 380–400 g CP/kg (Thacker, 1990b). The lysine content of canola meal is lower and the methionine content is higher than in soybean meal. Otherwise it has a comparable AA profile to soybean meal. However, the AA in canola meal are generally less available than in soybean meal (Aherne and Kennelly, 1985; Thacker, 1990b). Canola meal must be properly processed to optimize the utilization of the protein.

Because of its high fibre content (> 110 g/kg), canola meal contains about 15–25% less DE than soybean meal (Thacker, 1990b). Dehulling can be used to increase the DE content. Compared with soybeans, canola seed is a good source of calcium, selenium and zinc, but is a poorer source of potassium and copper. Canola meal is generally a better source of many minerals than soybean meal but high phytic acid and fibre contents reduce the availability of many mineral elements. It is a good source of choline, niacin and riboflavin, but not folic acid or pantothenic acid. Canola meal contains one of the highest levels of biotin found typically in North American ingredients. Total biotin in canola meal was found to average 1231 μg/kg with bioavailability of 0.71 (Misir and Blair, 1988). The choline level was reported to be approximately three times higher in canola than soybean meal, but in a less available form (Emmert and Baker, 1997).

Cold-pressing of canola has been tested in Australia (Mullan *et al.*, 2000). This process resulted in a meal with a higher content of oil and glucosinolates than expeller canola. The DE (MJ/kg, air-dry basis) was 16.57, compared with 14.23 in expeller canola meal and 12.41 in solvent-extracted meal. Total AA levels appeared to be relatively unaffected by the oil extraction process or degree of heat treatment.

ANTI-NUTRITIONAL FACTORS Glucosinolates represent the major anti-nutritional factor found in canola, occurring mainly in the embryo. This feature limited the use of rapeseed or rapeseed meal in pig diets in the past. Although glucosinolates themselves are biologically inactive, they can be hydrolysed by myrosinase in the seed to produce goitrogenic compounds that affect thyroid gland function. These cause the thyroid gland to enlarge, resulting in goitre. They can also result in liver damage and can have a negative effect on reproduction. Fortunately the modern cultivars of canola contain only about 15% of the glucosinolates found in rapeseed. In addition, heat processing is effective in inactivating myrosinase. An estimate of the tolerable level of glucosinolates in the total diet of pigs is 2.4–2.5 μmol/g (Bell, 1993; Schöne *et al.*, 1997a,b). A cold-pressed canola meal containing 96 g oil and 10.5 μmol total glucosinolates per kg (oil-free DM basis) was included in diets for growing-finishing pigs at levels of 0, 50, 100, 150 and 200 g/kg at the expense of sweet lupin seed (Mullan *et al.*, 2000). Results showed that at levels of canola meal in the diet above 150 g/kg, the performance of growing-finishing pigs was depressed and thyroid hypertrophy was evident. These results suggest that cold-pressing does not inactivate myrosinase sufficiently to allow the extracted meal to be incorporated into pig diets at maximum levels.

Tannins are present in some varieties of canola but only at very low levels (Blair and Reichert, 1984). Canola, rapeseed and soybean hull tannins are not capable of inhibiting α-amylase (Mitaru *et al.*, 1982), in contrast to those in other feedstuffs such as sorghum. Sinapine is the major phenolic constituent of canola and, although bitter-tasting (Blair and Reichert, 1984), is not regarded as presenting any practical problems in pig feeding. It occurs mainly in the seed germ.

PIG DIETS The response of pigs of all ages to canola meal inclusion in diets is generally favourable. Most of the published research has been conducted using commercial solvent-extracted meal. The results can be used as a guide to the use of expeller canola meal in pig feeding, provided the differences in composition between the two types are taken into account in formulating the diets.

Until recently the standard recommendation was that canola meal can be included in grower diets to supply up to 50% of the supplementary protein required. This was based on older findings that feed conversion efficiency and rate of gain were decreased when canola replaced more than 75% of soybean meal in pig diets (Baidoo *et al.*, 1987). More recent results from Europe suggest this limit may be too conservative. Roth-Maier *et al.* (2004) reported no effects on the feed intake or growth performance of growing pigs (30–60 kg) when canola meal replaced all of the supplementary protein. The higher limits suggested by this research may be attributable to a lower level of glucosinolates in the canola meal used, 8.3 μmol/kg. Another rationale for the possible adoption of higher limits is that better results are obtained when the diets are formulated on the basis of digestible AA. It is now known that the true ileal digestibility coefficients of EAA are lower in canola (about 0.8) than in soybean meal (about 0.9) (Heartland Lysine Inc., 1998). When the dietary AA are balanced to the same levels of digestible lysine, growth is similar with these two protein supplements (Siljander-Rasi *et al.*, 1996; Raj *et al.*, 2000).

For finishing pigs, most of the published data indicate that canola meal can be used to supply the entire supplementary protein, provided the diets containing canola are formulated on the basis of digestible AA as described above. A complete replacement of soybean meal with canola meal typically has no effect on feed intake, growth performance or carcass quality of pigs. Research conducted in Mexico confirmed these conclusions (Hickling, 1996). The canola meal used was produced by Mexican oilseed crushers from Canadian canola seed and incorporated into diets based on local sorghum or maize. Equivalent growth, feed efficiency and carcass quality performance were obtained with diets containing zero, medium or a high level of canola meal.

The data available on the use of canola meal in sow diets are limited. Reproductive performance appeared to improve as the level of glucosinolates in the rapeseed meal decreased (Aherne and Kennelly, 1985). Flipot and Dufour (1977) found no difference in reproductive performance between sows fed diets with or without 100 g added canola meal per kg. One study found that canola meal could be used as the only protein supplement for pregnant and lactating females for at least two reproductive cycles without any adverse effects on reproductive performance (Aherne and Kennelly, 1985; Thacker, 1990b). King *et al.* (2001) fed 386 mixed-parity sows on diets containing Australian canola meal at 0, 101 and 202 g/kg during a lactation period of about 25 days. The average composition (per kg) of the canola meal used was 884 g DM, 376 g CP, 41 g fat, 21.6 g lysine and 12.4 MJ DE; glucosinolates 4.5 mmol/g. The canola meal replaced other sources on an equivalent DE and lysine basis. Average piglet growth between day 3 and weaning was 244 g/day and was unaffected by inclusion level of canola meal in the sow diet. An interesting finding was that average feed intake during lactation was 5.08, 5.50 and 5.67 kg/day for sows fed diets with canola meal at 0, 101 and 202 g/kg, respectively, the increase in intake being particularly evident when environmental temperature was higher. These results suggest that all of the supplementary protein in sow diets can be from canola meal.

Full-fat canola (canola seed)

A more recent approach with canola is to include the unextracted seed in pig diets, as a convenient way of providing both supplementary protein and energy. Good results have been achieved with this feedstuff, especially with the lower-glucosinolate cultivars. However, there are two potential problems that need to be addressed, as with full-fat soybeans. The maximum nutritive value of full-fat canola is obtained only when the product is mechanically disrupted and heat-treated to allow glucosinolate destruction and to expose the oil contained in the cells to the lipolytic enzymes in the gut (Smithard, 1993). Once ground, the oil in full-fat canola becomes highly susceptible to oxidation, resulting in undesirable odours and flavours. The seed contains a high level of α-tocopherol (vitamin E), a natural antioxidant, but additional supplementation with an acceptable antioxidant is needed if the ground product is to be stored. A practical approach to the rancidity problem would be to grind just sufficient canola for immediate use.

Thacker (1998) found that micronization of intact canola seed increased the growth rate and feed intake of gilts fed diets containing canola seed. The improvement in growth rate was attributed to a reduction in myrosinase activity, reducing the opportunity for hydrolysis of glucosinolates in the gut.

Aherne and Bell (1990) reviewed the use of canola seed in pig diets and concluded that a dietary level up to 200 g/kg had no effect on the growth performance of grower-finisher pigs but that more than 100 g/kg led to a softer backfat in the carcass with an increased degree of polyunsaturation. These results are similar to those found with full-fat soybeans. Inclusion levels of 160 g/kg in diets for grower-finisher pigs were recommended by Australian researchers for maximum growth efficiency (Brand *et al.*, 1999). However, the backfat of pigs consuming diets with 160 and 240 g full-fat canola/kg had 13% higher iodine numbers (a measure of fat unsaturation) than pigs that received diets with 0 and 80 g full-fat canola/kg. Generally, all saturated fatty acids in the backfat decreased, while monounsaturated and polyunsaturated fatty acids increased, with increasing levels of canola in the diets. Thus full-fat canola is generally limited to 100 g/kg in diets for growing-finishing pigs.

Raw canola seed was incorporated in sow diets at levels of 0–250 g/kg, commencing at day 109 of gestation and continuing until 21 days after farrowing (Spratt and Leeson, 1985). Reproductive performance was not affected by level of canola seed up to 100 g/kg and there was no effect on feed intake during lactation. However, voluntary feed intake was reduced when the inclusion level reached 150 g/kg, which resulted in a higher weight loss in the sows. Piglets weighing < 1.25 kg at birth were heavier at weaning with sows fed 150 g canola seed/kg because of a higher milk fat content. In more recent work Smiricky-Tjardes *et al.* (2003) investigated the effects of including either full-fat canola or canola meal in diets fed to gestating and lactating swine. A control diet was based on maize and soybean meal. Gestation diets were formulated to contain 140 g CP/kg and lactation diets to contain 180 g CP/kg. During gestation all sows were fed to receive 7000 kcal/day and during lactation they were fed *ad libitum*. Feeding of the experimental diets began right after breeding and continued through two reproductive cycles. Sows receiving the full-fat canola diet gained less weight during gestation than sows receiving the other two diets. However, they also lost less weight during lactation than sows receiving the canola meal diet. The number of pigs born alive was higher for sows receiving either the maize/soybean meal or maize/full-fat canola diet. Weight of pigs born alive and litter birth weight did not differ among dietary treatments, nor did return to oestrous interval. The authors concluded that a diet based on maize and full-fat canola gave similar results as a diet based on maize and soybean meal when fed to gestating and lactating sows.

On the basis of these and related findings it is suggested that the level of full-fat canola in sow diets be limited to 100 g/kg and that the seed be subjected to some form of heat treatment either before or during feed manufacture.

Cottonseed meal (*Gossypium* spp.)

Cottonseed is important in world oilseed production, major producing countries being the USA, China, India, Pakistan, Latin America and Europe. It is the second most important protein feedstuff in the USA. Most of the cottonseed meal is used in ruminant diets, but it can be a good source of protein for pig diets when its limitations are considered (Tanksley, 1990; Chiba, 2001).

NUTRITIONAL FEATURES The nutrient content of cottonseed meal was reviewed by Tanksley (1990) and Chiba (2001). According to these reviews the CP content of cottonseed meal may vary from 360 to 410 g/kg, depending on the contents of hulls and residual oil. AA content and digestibility of cottonseed meal are lower than in soybean meal. Although fairly high in protein, cottonseed meal is low in lysine and tryptophan. AA digestibility is low for lysine in screw-press meal (Tanksley, 1990), perhaps because of the formation of an insoluble complex between the ϵ-amino group of lysine and free gossypol with heating. The fibre content is higher in cottonseed meal than soybean meal, and its DE value is inversely related to the fibre content. Cottonseed meal is a poorer source of minerals than soybean meal. The content of carotene is low in cottonseed meal, but this meal compares favourably with soybean meal in water-soluble vitamin content, except biotin, pantothenic acid and pyridoxine.

ANTI-NUTRITIONAL FACTORS The inclusion of cottonseed meal in pig diets is limited because of the deleterious effects produced by the residual free gossypol found in the pigment glands of the seed. This problem does not occur in glandless cultivars of cottonseed. Gossypol can be classified into bound gossypol, which is non-toxic to non-ruminant species, and free gossypol, which is toxic. The general signs of gossypol toxicity are constipation, depressed appetite, loss of weight and death from circulatory failure. Toxicity signs usually occur when free gossypol levels in the diet approach 100 mg/kg (Tanksley, 1990). The free gossypol content of cottonseed meal decreases during processing and varies according to the methods used. In new seed, free gossypol accounts for 0.4–1.4% of the weight of the kernel. Screw-pressed materials have

200–500 mg free gossypol/kg. Processing conditions have to be controlled to prevent loss of protein quality owing to binding of gossypol to lysine at high temperatures. Fortunately the shearing effect of the screw press in the expeller process is an efficient gossypol inactivator at temperatures which do not reduce protein quality (Tanksley, 1990).

A general recommendation is that cottonseed meal should replace no more than 50% of the soybean meal or protein supplement in the diet, on a digestible lysine basis (Chiba, 2001). At this inclusion rate, it is unlikely that the total diet will contain more than the toxic level of free gossypol. Iron salts, such as ferrous sulphate, are effective in blocking the toxic effect of dietary gossypol, possibly by forming a strong complex between iron and gossypol and thus preventing gossypol absorption. It is probable that gossypol reacts with iron in the liver, and the iron–gossypol complex is then excreted via the bile. A 1:1 weight ratio of iron to free gossypol can be used to inactivate the free gossypol in excess of 100 mg/kg (Tanksley, 1990). However, it is unlikely that this treatment would be acceptable for organic pig diets. A more acceptable approach would be the use of glandless cotton cultivars devoid of gossypol, if available.

PIG DIETS The use of cottonseed meal in pig diets was reviewed by Tanksley (1990) and Chiba (2001). These authors recommended that three characteristics of glanded cottonseed meals need to be taken into account in diet formulation: the low lysine, high CF and free gossypol contents. On the basis of a typical analysis, it follows that that the safe upper limit for a good screw-press meal is about 200 g/kg. According to these reviews the use of glanded cottonseed meal as the only supplemental protein in cereal-based diets for grower-finisher pigs is likely to result in lower pig performance than with soybean meal-based diets. However, many studies have shown that excellent pig performance can be obtained when cottonseed meal is fed in combination with other high-quality protein supplements. Compared with soybean meal, the availability of ileal digestible nitrogen from cottonseed meal is lower (Prawirodigdo *et al.*, 1997). Dietary supplementation with lysine has been shown to improve the AA digestibility and biological value of cottonseed meal, and further supplementation with threonine and tryptophan improved the digestibility of several AA (Feggeros *et al.*, 1992).

Digestibility of AA was found to be higher for glandless than glanded cottonseed meal (Tanksley, 1990). LaRue *et al.* (1985) observed similar or higher digestibility of nitrogen and all EAA, except lysine, for glandless cottonseed meal compared with soybean meal. They concluded that glandless cottonseed meal supplemented with lysine could be used to replace at least 40% of the supplemental protein without affecting the performance of growing pigs. Zongo and Coulibaly (1993) suggested that glandless cottonseed meal supplemented with lysine could totally replace soybean meal in finisher diets without affecting pig performance. Results reported by Dove (1998) suggest that finishing pigs can be fed diets containing up to 150 g cottonseed meal/kg with no adverse effects on growth performance or carcass quality. An experiment was conducted in Cameroon to determine the effects of including cottonseed cake in diets for growing pigs (Fombad and Bryant, 2004). Landrace × Large White pigs were killed when they reached a live weight of 75 kg. Inclusion of cottonseed cake reduced voluntary feed intake and live-weight gains and increased heart, kidney and liver weights. Pigs fed a soybean-based control diet took the shortest time to reach slaughter weight. The result was attributed in part to a lysine deficiency in the cottonseed diets and in part to the effect of free gossypol. The researchers concluded that weaner-grower diets could contain cottonseed cake up to 300 g/kg.

Reports suggest that cottonseed meal can replace up to half the soybean meal in sorghum/soybean meal gestation and lactation diets (Tanksley, 1990). However, based on the lower weaning weight observed in a study conducted by Haught *et al.* (1977), Tanksley (1990) suggested that lactation diets should contain less than 50% of the supplemental protein in the form of cottonseed meal. Limiting cottonseed meal to supply

25% of the supplemental protein was considered likely to result in satisfactory reproductive productivity.

Linseed (*Linum usitatissimum*)

Linseed (flax) is grown mainly to produce linseed oil for industrial applications, with western Canada, China and India being leading producers. Other important areas of production are the Northern Plains region of the USA (Maddock *et al.*, 2005), Argentina, the former USSR and Uruguay. Flax is grown typically under dryland conditions. In Canada, flax is produced only as an industrial oilseed crop and not for textile use as in some countries.

The oil content of flaxseed ranges from 400 to 450 g/kg and the by-product of mechanical oil extraction – flaxseed (or linseed) meal – can be used in organic pig feeding. There is also interest in feeding the ground whole oil-containing seed to pigs for two main reasons: to produce meat with a fatty acid profile in the fat that confers health benefits to the consumer and to impart an enhanced flavour to the meat.

NUTRITIONAL FEATURES As with most grains and oilseeds, the composition of flax varies depending on cultivar and environmental factors. Typical values are 460 g EE/kg and 220 g CP/kg (DM basis) (DeClercq, 2006). Reported CP values range from 188 to 244 g/kg (Daun and Przybylski, 2000). A large study in Poland found that the average EE content was 321.4 g/kg in organic flax compared with 324.2 in conventional flax (Grela and Semeniuk, 2008). The corresponding values for CP, CF and ME were 221.2 and 229.1 g/kg, 106.5 and 105.8 g/kg, and 20.8 and 21.4 MJ/kg DM, respectively. Jacob (2007) reported similar values for CP in organic and conventional flaxseed, i.e. 218.1 and 220 g/kg respectively. As with other oilseeds, mechanical extraction results in a higher residual oil content in the meal than in the solvent-extracted product. As reviewed by Maddock *et al.* (2005), several reports have indicated possible human health benefits associated with consumption of flaxseed. Per kg, the oil contains about 230 g α-linolenic acid (ALA), an essential n–3 fatty acid that is a precursor for eicosapentaenoic acid (EPA), and about 65 g linoleic acid. EPA is a precursor for the formation of eicosanoids, which are hormone-like compounds that play an essential role in the immune response. Additionally, some evidence suggests EPA can be converted to docosahexaenoic acid (DHA), an n–3 fatty acid that is essential for cell membrane integrity, as well as brain and eye health. Flax is the richest plant source of the lignan precursor secoisolariciresinol diglycoside, which is converted by microorganisms in the hindgut of pigs and other non-ruminants to mammalian phyto-oestrogens (Kitts *et al.*, 1999). Phyto-oestrogens are believed to have potential uses in hormone replacement therapy and cancer prevention (Harris and Haggerty, 1993). Recent research indicates that products from animals fed flax have increased levels of n–3 fatty acids (Maddock *et al.*, 2005).

The nutrient content of linseed meal has been reviewed by Chiba (2001) and Maddock *et al.* (2005). The CP content averages 350–360 g/kg, but may vary from 340–420 g/kg. Linseed meal is deficient in lysine and contains less methionine than other oilseed meals (Aherne and Kennelly, 1985). Because of the hulls, which are coated with high quantities of mucilage, the CF content of linseed meal is relatively high. The mucilage contains a water-dispersible carbohydrate which has low digestibility for non-ruminant species (Aherne and Kennelly, 1985; Batterham *et al.*, 1991). The major macro minerals in linseed meal are comparable with those in other oilseed meals, although the levels of calcium, phosphorus and magnesium are higher than the levels found in soybean meal (Bowland, 1990). Although micro minerals in linseed meal vary widely, it is a very good source of selenium (Bowland, 1990), possibly because it has been grown in selenium-adequate areas. The water-soluble vitamin content of linseed meal is similar to that of soybean meal and most other oilseed meals (Bowland, 1990).

ANTI-NUTRITIONAL FACTORS Flaxseed or linseed meal contains a number of anti-nutritional factors for livestock, the main ones being linamarin and linatine (Bowland, 1990; Batterham *et al.*, 1991). Linamarin is a cyanoglycoside, which has the potential to cause cyanide poisoning by the action of the enzyme linamarase (linase). However, these factors do not pose a major problem to pigs. The mature seed contains little or no linamarin; also this enzyme is normally destroyed by heat during oil extraction. In addition, when dry meal containing linamarase is consumed by pigs the enzyme is inactivated by the acidic conditions in the stomach before it can act on linamarin (Bowland, 1990). Linatine is a dipeptide that can act as an antagonist for pyridoxine, and it has been postulated that diets containing linseed meal may be marginally deficient in this vitamin (Bowland, 1990). However Batterham *et al.* (1994) reported no benefits in pigs fed flax-based diets supplemented with pyridoxine at the rate of 100 mg/kg.

PIG DIETS The use of linseed meal in pig diets has been reviewed by Seerley (1991), Chiba (2001) and Maddock *et al.* (2005). These reviews showed that linseed meal could be fed to young pigs at low levels (30 g/kg) in the diet and that older pigs seem to be able to utilize higher levels. Seerley (1991) suggested that linseed meal could be used to best advantage at a level of up to 50% of the protein supplement. Because it is deficient in lysine, linseed meal should be used in combination with a complementary protein source(s). Bell and Keith (1994) reported that an inclusion rate of 50 g linseed meal/kg reduced efficiency of feed and DE utilization in growing pigs. More recent results suggest that linseed meal can be used at levels between 50 and 150 g/kg in diets for growing-finishing pigs provided that the diet has been balanced for digestible AA (Li *et al.*, 2000; Eastwood *et al.*, 2009). Inclusion of the meal has the benefit of increasing the n-3 fatty acid content of the meat.

The mucilage in linseed meal is indigestible by non-ruminant species, but it can absorb a large amount of water. Thus, linseed meal may have a laxative effect and be beneficial in preventing constipation in sows at parturition (Seerley, 1991). There appears to be a lack of published data on the use of linseed meal for gestating and lactating sows, but Bowland (1990) suggested that at least 100 g linseed meal/kg could be included in sow diets, provided the diets are balanced correctly for lysine.

Flaxseed

Several studies have been conducted on the whole seed as a feed ingredient for pigs, for reasons explained above. As with other oilseeds containing oil that is subject to rancidity, the ground seed should be mixed into diets and used quickly after processing. Romans *et al.* (1995a,b) fed ground flax at 0, 50, 100 and 150 g/kg diet for the final 7, 14, 21 or 28 days prior to slaughter and reported no differences in growth performance or carcass traits in pigs. Neither study reported differences in fat firmness or lean quality. Both studies indicated that flax inclusion in the diet increased the ALA and EPA concentrations in muscle and fat tissues, and that concentrations increased over time and as dietary level increased. Trained panellists rated bacon from flax-fed pigs as more flavour-intense than from control pigs. However, more flavour defects were recorded for bacon from flax-fed pigs and a 105-member consumer group recorded a higher frequency of ‘dislikes’ for bacon from flax-fed pigs than from control pigs.

Matthews *et al.* (2000) used diets containing 0, 50 and 100 g flaxseed/kg for growing-finishing pigs and reported a slight difference in feed intake but no effects on production characteristics or carcass traits. Levels of ALA were increased in all tissues studied as the amount of flaxseed in the diet increased. EPA concentration increased markedly in plasma, longissimus thoracis muscle, and in liver and kidney. Docosapentaenoic acid concentration increased in the muscle, liver and kidney, whereas higher levels of DHA were observed in the plasma. Feeding whole flaxseed had no negative effect on the oxidative stability of the meat. Sensory panel results showed no significant differences due to diet except for a reduction in abnormal odour (odour perceived by panellists to be abnormal in the pork) with the diet containing 50 g/kg and a reduction in the skatole odour (odour of 3-methylindole) in pork from the pigs fed the diet containing 100 g/kg. These authors concluded that increasing the flaxseed content of pig diets up to 100 g/kg has no adverse effect on the carcass or meat quality whilst enhancing the concentrations of n–3 fatty acids which have a potentially positive health effect in humans.

Kouba *et al.* (2003) fed growing pigs on diets containing crushed flax at 60 g/kg for 20, 60 or 100 days and found no differences in growth rate or carcass composition when compared with pigs fed diets based on wheat and soybean meal. This study confirmed that pigs fed flaxseed had higher muscle ALA and EPA concentrations than pigs fed a control diet, but that ALA levels decreased between 60 and 100 days in pigs fed the flax diet. Levels of EPA decreased over time regardless of dietary treatment.

In a large study involving over 7000 sows, Lawrence *et al.* (2004) included rolled flaxseed at 50 g/kg in sow diets and reported that flax addition decreased weaning-to-oestrus interval (8.0 versus 7.4 days) and pre-weaning mortality (13.7 versus 10.0%). In addition pigs weaned per mated sow were increased (20.8 versus 20.3, annual production). The results were interpreted as supporting the hypothesis that addition of flaxseed induced hormonal responses that improved the number of pigs weaned per litter and per sow per year. Additionally, Stitt (1992) noted that feeding gilts and sows flax at 75 g/kg diet over two generations increased litter size (7.47 versus 10.93, control versus flax).

Mustard

Mustard is both a condiment and an oilseed crop. It grows well in temperate and in high-altitude, subtropical areas and is moderately drought-resistant (Bell, 1990). Two species are grown: *Brassica juncea* (brown and oriental mustard) and *Sinapis alba* (yellow or white mustard). *B. juncea* is grown as an edible oil crop in China, India, Russia and Eastern Europe. Canada is the world's largest supplier of mustard seed, exporting the seed to Japan, the USA, Europe and Asia. Newer mustard cultivars appear to have several advantages over some of the canola cultivars being grown, being higher-yielding in most parts of western Canada, early maturing, more resistant to late spring frosts, more heat- and drought-tolerant, more resistant to seed shattering, and more resistant to disease.

NUTRITIONAL FEATURES Some of these new low-glucosinolate cultivars can be considered as alternatives to canola as an oilseed crop, since the meal appears similar to canola meal in nutrient content. The new cultivars of mustard are also of interest in Australia.

Bell *et al.* (1998) studied the digestibility of canola and mustard meals in finishing pigs. The CP contents (g/kg) were as follows: Excel canola 418, Parkland canola 401 and *B. juncea* 439. Estimates of the DE (kcal/kg) were, on a DM basis: Excel canola 3120, Parkland canola 3375, *B. juncea* 3340 and soybean meal 3815 (13.0, 14.1, 13.9 and 15.9 MJ/kg, respectively). These values agreed with those of the NRC (1998) for soybean meal and commercial canola meal. These researchers concluded that meal derived from *B. juncea* (line J904253) was similar to that from Parkland canola meal in terms of DE and digestible protein content.

PIG DIETS Bell (1990) concluded that mustard meal can be included successfully in sow diets at up to 50 g/kg and in diets for finishing pigs at up to 100 g/kg. Some studies showed reduced conception and irregular oestrus at time of first breeding, related probably to high glucosinolate content in the mustard meal used. A recent study at the Prairie Swine Centre, Canada, indicated that the mustard meal now available for feed use has a nutritional value equal or superior to that of canola for growing pigs (Zijlstra *et al.*, 2004a). Pelleted diets (per kg basis) containing 150 g canola or mustard meals were used, based on 480 g maize, 170 g soybean meal and 150 g wheat. They contained 3.45 Mcal DE/kg and 2.60 g apparent digestible lysine/Mcal DE. For each of the four weeks of the experiment, voluntary or average daily feed intake increased gradually, and differences in feed intake were not observed between pigs fed diets based on mustard meal or canola meal. For the first three weeks of the experiment, average daily gain and feed efficiency did not differ statistically between pigs fed mustard meal or canola meal. However, pigs fed mustard meal grew faster and with a higher feed efficiency during the final week of the experiment. As a result, there was an overall tendency for pigs fed the diets based on mustard meal to grow faster than the pigs fed diets based on canola meal. The findings confirm the quality of feed-grade mustard meal as a feed ingredient for pigs and suggest that pigs may require an adaptation period to adjust to the inclusion of this feedstuff in the diet.

Groundnuts (*Arachis hypogaea* L.)

Groundnuts (also known as peanuts) are not included as an approved feedstuff in either the EU or New Zealand lists but should be acceptable for organic pig diets if grown organically. The reason for omission may be that groundnuts are grown mainly for the human market. This crop is grown extensively in tropical and subtropical regions and is too important to be rejected for use in organic pig diets. However, this issue should be clarified with the local certifying agency. China and India are the largest producers of groundnuts. Groundnuts not suitable for human consumption are used in the production of groundnut (peanut) oil. The by-product of oil extraction, groundnut meal, is widely used as a protein supplement in livestock diets (Aherne and Kennelly, 1985; Chiba, 2001).

NUTRITIONAL FEATURES The nutrient contents of groundnuts and extracted groundnut meal were reviewed by Chiba (2001). Raw groundnuts contain 400–550 g oil/kg. Groundnut meal is the ground product of shelled groundnuts, composed principally of the kernels, with such portion of the hull, or fibre, and oil remaining after oil extraction by a mechanical extraction process. Mechanically extracted meal may contain 50–70 g oil/kg, thus it tends to become rancid during storage, especially during summer. In the USA the meal is usually adjusted to a standard protein level with ground groundnut hulls. The traded product in the USA must contain no more than 70 g CF/kg and only such amount of hulls as is unavoidable in good factory practice. The CP content of extracted meal ranges from 410 to 500 g/kg. Groundnut protein is deficient in lysine and is low in methionine and tryptophan. Thus it is not suitable as the sole supplemental protein for pig diets and needs to be mixed with other protein sources (Braude *et al.*, 1974). Groundnut meal is low in calcium, sodium and chloride and much of the phosphorus occurs as phytate. It is a good source of niacin, thiamin, riboflavin, pyridoxine, pantothenic acid and choline.

ANTI-NUTRITIONAL FACTORS Newton *et al.* (1990) and Chiba (2001) reviewed the anti-nutritional factors present in groundnut kernels. Groundnuts contain protease inhibitors and tannins, but generally not at levels high enough to cause concern. Heat processing of whole groundnuts was found to reduce trypsin inhibitor activity, but it had no effect on pig performance (Balogun and Koch, 1979a). Tannins may be associated with relatively low protein digestibility of groundnut meals. Groundnuts are subject to contamination with moulds. *Aspergillus flavus*, which produces aflatoxin, can grow in groundnuts and occur in groundnut meal. Aflatoxin is carcinogenic and acutely toxic to animals and humans, depending on the level of contamination (see section on Mycotoxins).

The use of whole groundnuts and groundnut meal in pig diets has been reviewed by Chiba (2001). Because of its low lysine content, using groundnut meal in combination with ingredients high in lysine appears to be the most effective way to utilize this protein supplement in pig diets. Replacing soybean meal completely with groundnut meal resulted in lower feed intake, slower growth rate and lower feed efficiency in pigs weaned at 15 days of age, and reduced digestion coefficients at 7–8 weeks of age (Combs *et al.*, 1963). Similarly, replacing 50 or 100% of soybean meal with groundnut meal in diets for 5-week-old starter pigs resulted in reduced growth performance (Orok *et al.*, 1975). The reduction in performance was possible due to an insufficiency of lysine in the diets, although lysine supplementation did not alleviate the growth depression of young pigs (Orok *et al.*, 1975). Grower-finisher pigs fed groundnut meal diets without AA supplementation grew slower than those fed soybean meal diets (Brooks and Thomas, 1959). Supplementation with lysine alone was partially effective in alleviating the growth depression and further supplementation with methionine alleviated the decrease completely. Iliori *et al.* (1984) reported no difference in performance of pigs fed diets containing 150–200 g groundnut meal plus 30–49 g blood meal per kg compared with pigs fed a soybean meal diet, confirming the need for supplemental sources of lysine and other AA when pig diets are based on groundnut meal as the protein source. Groundnut meal is a good protein source for pig diets in countries such as Nigeria that are able to grow this crop, and has been shown to be superior to cottonseed cake for use in maize-based diets for growing pigs (Mafimidiwo *et al.*, 1998).

PIG DIETS Whole groundnuts surplus to human needs or of a grade unacceptable for human use can be used as feedstuffs for pigs. Both raw and processed kernels are used. Haydon and Newton (1987) reported that a dietary inclusion of roasted groundnut kernels at a level of 50 g/kg appeared to be optimal for weanling pigs. A similar inclusion level of raw or roasted groundnuts on an equal lysine basis was suggested by Newton and Haydon (1988) for growing pigs. For growing-finishing pigs it was suggested that roasted or raw groundnuts should be limited to less than 100 g/kg diet because of their adverse effects on carcass quality (Newton *et al.*, 1990; Chiba, 2001). Balogun and Koch (1979b) found that a dietary inclusion of full-fat groundnuts at 100, 150 or 200 g/kg had no effect on growth performance or nutrient digestibility in growing pigs. However, the animals fed diets containing 200 g whole groundnuts/kg had inferior carcass quality compared with those on a soybean meal diet. A study was conducted to evaluate raw cull groundnuts as a potential fat source when included at a 100 g/kg level in diets for growing and finishing pigs (Myer and Gorbet, 1998). The trial involved pigs from an initial weight of 30 kg to market weight (109 kg). Two cultivars of groundnuts were compared, one containing a high content of oleic acid. A control diet was based on soybean meal and maize and was supplemented with 45 g fat/kg. Pig growth, feed efficiency and calculated carcass lean content were not affected by diet. Carcass fat firmness decreased slightly for pigs fed groundnut diets compared with pigs fed the diet with added fat. However, average firmness scores indicated that the carcass fat was acceptable by the meat processor. These results suggest that raw cull groundnuts at 100 g/kg diet appear to be utilized well as a protein and fat source, with minimal negative effect on carcass fat firmness. There are anecdotal reports of improved meat flavour in pigs grazing on fields following groundnut harvesting, but these claims do not appear to be confirmed by published research.

Full-fat groundnut meal has also been investigated as a feedstuff for pigs. Whole groundnuts were found to be a good source of dietary fat and protein for lactating sows. Haydon *et al.* (1990) conducted a lactation trial to determine the effect of a 120 g/kg inclusion of roasted or raw, ground, whole, shelled groundnuts on sow productivity over two farrowings. Diets were based on maize and soybean meal with either 50 g animal fat/kg or equivalent added fat from peanuts. The replacement of animal fat by roasted or raw groundnuts had no effect on sow weight change, average daily feed intake during lactation, days to oestrus post-weaning, or on piglet weight gain or survival.

Safflower meal (*Carthamus tinctorius*)

Safflower is an oilseed crop cultivated in tropical regions. Safflower oil is high in PUFA, particularly linoleic acid, making it an important oil for human use, like canola and olive oils. India, the USA and Mexico are major producers of safflower. However, it can be grown in cooler areas. Because it is a long-season crop, safflower extracts water from the soil for a longer period than cereal crops, and the long taproot can draw moisture from deep in the subsoil. These properties can help prevent the spread of dryland salinity in areas such as the Canadian prairies, using up surplus water from areas that otherwise would contribute to the development or expansion of salinity. Safflower meal is not included in the above lists of approved feedstuffs but should be acceptable if produced organically.

NUTRITIONAL FEATURES Chiba (2001) reviewed the nutrient content of safflower seed and meal. The seed is composed of approximately 400 g hull/kg, about 170 g CP/kg and 350 g crude fat/kg (Seerley, 1991). It is composed of a kernel surrounded by a thick fibrous hull that is difficult to remove. As a result much safflower meal is made from unhulled seed, suitable only for feeding to ruminants. Australian researchers (Ashes and Peck, 1978) described a simple mill and screening device for dehulling safflower seed and other seeds and grains. The device operates by bouncing the seed between a 'squirrel cage' type rotor and a ripple plate, thus forcing the hull from the kernel in contrast to conventional milling or rolling. Thirteen seed and grain types were dehulled during a single pass through the mill and screening device. Safflower seed was effectively dehulled by the device but required two passes through the mill. The efficiency of dehulling with other seeds and grains after one pass varied, but was 90% with sunflower seed and 95% with cottonseed. The extent of the dehulling was proportional to the velocity of the rotor tips and could be varied readily. Results showed that the mill was able to process a wide variety of seeds and also other ingredients such as dry lucerne hay. The Australian device may be of interest to organic pig producers who wish to grow their own protein feedstuffs such as safflower.

Oil extraction produces an undecorticated (hulled) safflower meal with approximately 200–220 g CP/kg and 400 g CF/kg. The undecorticated meal is also called whole pressed seed meal, whereas the decorticated meal is referred to as safflower meal. Decortication of the hulled meal yields a high-protein (420–450 g CP/kg), less fibrous (150–160 g CF/kg) meal, which is more suitable for inclusion in pig diets (Darroch, 1990).

Safflower meal is a poor source of lysine, methionine and isoleucine for pigs, the low level and availability of lysine being major factors contributing to the overall low nutritive value of the protein (Darroch, 1990). The mineral content of safflower meal is generally less than that of soybean meal, but safflower meal is a comparable source of calcium and phosphorus (Aherne and Kennelly, 1985). Safflower meal is a rich plant source of iron (Darroch, 1990). Compared with other oilseed meals, safflower meal has a relatively poor vitamin profile, but it is a good source of biotin, riboflavin and niacin relative to soybean meal (Darroch, 1990).

ANTI-NUTRITIONAL FACTORS Safflower meal contains two phenolic glucosides: matairesinol-β-glucoside, which gives a bitter flavour, and 2-hydroxyarctiin-β-glucoside, which has cathartic properties (Darroch, 1990). Both glucosides are associated with the protein fraction of the meal; they can be removed by extraction with water or methanol, or by the addition of β-glucosidase.

PIG DIETS There are limited data on the use of safflower meal as a protein supplement in pig diets. Decortication of the meal improves the nutritional value of the safflower meal for pigs, and the remaining discussion will deal with the use of dehulled meals. Safflower meal does not appear to be suitable as the sole source of supplementary protein for weanling pigs, and Williams and Daniels (1973) made a similar conclusion with regard to growing-finishing pigs. Therefore safflower meal should be used in conjunction with a protein source high in lysine and should be restricted to pigs weighing more than 45 kg live weight. Williams and O'Rourke (1974) reported that finisher female pigs fed safflower meal diets supplemented with AA showed a reduced growth rate, and a small increase was observed when the diet was supplemented with fishmeal instead of lysine and methionine.

Seerley (1991), in his review, suggested that safflower meal should not provide more than 5–10% of the supplemental protein in grower-finisher pig diets. On the basis of the available evidence Darroch (1990) suggested that safflower meal could be included up to 150 g/kg in the diet of pregnant females, but it should be limited to very low levels for lactating sows.

Sesame meal (*Sesamum indicum*)

Sesame is grown mainly in China, India, Africa, South-east Asia and Mexico as an oil crop. It is known as the 'queen of the oilseed crops' because of the excellent culinary properties of the oil (Ravindran and Blair, 1992). After oil extraction the meal can be used for animal feeding. Sesame meal is not of significant importance for pig feeding, however.

NUTRITIONAL FEATURES Chiba (2001) reviewed the nutrient properties of sesame seed and meal. Per kg, the seed contains on average 250 g CP, 500 g oil, 40 g CF, 50 g ash and 50 g moisture. The nutrient composition of dehulled, expeller-extracted meal is similar to that of soybean meal, with an average CP content of 400 g/kg and a CF value of 65 g/kg (Ravindran and Blair, 1992). Sesame meal is an excellent source of methionine, cystine and tryptophan, but it is low in lysine. Although sesame meal is a good source of minerals such as calcium, the availability may be low because of high levels of oxalates and phytate acids in the hull (Ravindran, 1991). Vitamin levels in sesame meal are comparable to those in soybean meal and most other oilseed meals (Ravindran, 1991).

ANTI-NUTRITIONAL FACTORS Although sesame seed is not known to contain any protease inhibitors or other anti-nutritional factors, high levels of oxalic and phytic acids may have adverse effects on palatability (Ravindran, 1991) and on availability of minerals and protein (Aherne and Kennelly, 1985). Decortication of seeds almost completely removes oxalates, but it has little effect on phytate (Ravindran, 1991). Complete decortication is difficult because of the small size of the seeds.

PIG DIETS Published information on the use of sesame meal in pig diets is limited (Chiba, 2001). Use of sesame meal in starter diets should be limited because of its high fibre content and possible palatability problems associated with phytates and oxalates (Ravindran, 1990). Cunha (1977) and Ravindran (1990) reviewed the available data for growing-finishing pigs and concluded that sesame meal could be utilized successfully, but that the inclusion rate depended on the type and quantity of other protein supplements in the diet. Seerley (1991) recommended that sesame meal should be blended with other high-lysine protein supplements, and could replace up to 10% of the soybean meal in maize/soybean meal diets for grower-finisher pigs and sows. More recent studies suggest that sesame meal is of limited value in pig diets. Li *et al.* (2000) conducted experiments to determine ileal digestibilities for the AA contained in sesame meal and then applied the values in a growth trial using growing-finishing pigs. In the digestibility trial Yorkshire × Landrace × Beijing Black pigs of 20 kg body weight were fed maize/soybean meal-based diets supplemented with sesame meal at 0, 250, 500 or 750 g/kg. With the exception of arginine and phenylalanine, the digestibility coefficients for the EAA declined as the level of sesame meal in the diet increased. In the growth trial Yorkshire × Landrace × Henan Min pigs of 22 kg body weight were fed on maize/soybean meal-based diets supplemented with 0, 30, 60, 90 or 120 g sesame meal/kg. Daily gain and feed conversion efficiency both declined linearly as the level of sesame meal in the diet increased. Tartrakoon *et al.* (2001) conducted a similar trial with diets based on soybean meal with or without sesame meal at 100 g/kg and formulated according to the apparent ileal digestibility of protein and AA in the dietary ingredients. There were no significant differences in total feed intake, average daily gain and feed conversion ratio among treatment groups. The results of nitrogen balance experiments in growing pigs showed that the pigs fed the diet based on sesame plus soybean meal had significantly lower total N excretion (g/day per pig) and urinary N : faecal N ratio than pigs fed the diet with soybean meal alone.

Sesame meal may have a role as a natural antioxidant in feeds for small-scale farmers using diets based on rice bran, which is very unstable and can become rancid on storage. Pig production is a very important source of cash income for small-scale farmers in the Mekong Delta area of Vietnam, where rice bran, broken rice, protein concentrate and vegetables, etc. are used for pig feeding. In this environment, rice bran, which is the major regional feed resource, must be used within a few weeks of production (Yamasaki *et al.*, 2003) because it is generally not de-fatted. As described in the section on rice bran, the oil is prone to peroxidation and loss of palatability. Yamasaki *et al.* (2003) tested the inclusion of ground white sesame at 10–35 g/kg into the diet of growing pigs and reported an improvement in feed intake and feed conversion efficiency. These researchers recommended the use of small amounts of sesame meal as a natural antioxidant for use with rice bran diets, but only when the sesame meal was fresh. Presumably the sesame meal acted in this way due to its content of vitamin E.

Soybeans (*Glycine max*) and soybean products

Soybeans and soybean meal are now used widely in animal feeding. The crop is grown as a source of protein and oil for the human market and for the animal feed market, with the USA, Brazil, Argentina and China being the main producers. Soybean meal is generally regarded as the best plant protein source in terms of its nutritional value. Also, it has a complementary relationship with cereal grains in meeting the AA requirements of farm animals. Consequently it is the standard to which other plant protein sources are compared (Cromwell, 1998).

Several genetically-modified strains of soybeans are now being grown; therefore organic producers have to be careful to select non-GM products. The major GM crops grown in North America are soybeans, maize, canola and cotton.

Whole soybeans contain 150–210 g oil/kg, which is removed in the oil extraction process. When the North American industry started in the 1930s, soybeans were mechanically processed using hydraulic or screw presses (expellers) to remove much of the oil. Later most of the industry converted to the solvent-extraction process. Disadvantages of the mechanical process are that it is less efficient than the solvent process in extracting the oil and that the heat generated by friction of the screw presses, while inactivating anti-nutritional factors present in raw soybeans, subjects the product to a higher processing temperature than in the solvent-extraction process, which may damage the protein. Expeller soybean meal is thus favoured for dairy cow feeding since the higher content of rumen by-pass protein results in improved milk production. Consequently most of the expeller soybean meal available is used in the dairy feed industry and may be difficult to obtain for the organic pig producer.

More recently a new process known as extruding-expelling has been developed. Extruders are machines in which soybeans or other oilseeds are forced through a tapered die. The frictional pressure causes heating. In the extruding-expelling process a dry extruder in front of the screw presses eliminates the need for steam. These plants are relatively small, typically processing 5–25 tonnes of soybeans per day in the US situation. The dry extrusion-expelling procedure results in a meal with greater oil content than in conventional solvent-extracted meal, but with similar low trypsin inhibitor values. The nutritional characteristics of extruded-expelled meal have been shown to be similar to those of screw-pressed meal, with Woodworth *et al.* (2001) showing that extruded-expelled soybean meal is more digestible than conventional soybean meal. These researchers also showed that extruded-expelled soybean meal could be used successfully in pig diets. This process should be of interest therefore to organic producers since the soy product qualifies for acceptance in organic diets.

Yet another process being used in small plants is extrusion, but without removal of the oil, the product being a full-fat meal. Often these plants are operated by cooperatives and should be of interest to organic producers since the product also qualifies for acceptance in organic diets. Another interesting development with soybeans is the introduction of strains suitable for cultivation in cooler climates, for instance the Maritime region of eastern Canada. This development, together with the installation of extruder plants, allows the crop to be grown and utilized locally, holding the promise for regions that are deficient in protein feedstuffs to become self-sufficient in feed needs. Developments such as this may help to solve the ongoing problem of an inadequate supply of organic protein feedstuffs in Europe.

NUTRITIONAL FEATURES Whole soybeans contain 360–370 g CP/kg, whereas soybean meal contains 410–500 g CP/kg depending on the efficiency of the oil extraction process and the amount of residual hulls present. The oil has a high content of the PUFA linoleic and linolenic acids. It also contains high amounts of another unsaturated fatty acid, oleic, and moderate amounts of the saturated fatty acids palmitic and stearic.

Jacob (2007) reported a slightly higher content of CP in organic soybeans and in expeller soybean meal than in conventional soybeans and expeller meal, 398.5 versus 380 g/kg and 431.3 versus 420 g/kg, respectively.

Conventional soybean meal is generally available in two forms, meal with 440 g CP/kg and dehulled meal, which contains 480–500 g CP/kg. Because of its low fibre content, the DE content of soybean meal is higher than in most other oilseed meals. Soybean meal has an excellent AA profile. The content of lysine in soybean protein is exceeded only in pea, fish and milk proteins. Soybean meal is an excellent source of tryptophan, threonine and isoleucine, complementing the limiting AA in cereal grains. In addition, the AA in soybean meal are highly digestible in relation to other protein sources of plant origin. Apparent digestibility of nitrogen and most AA has been shown to be similar for both types of soybean meal. These features allow the formulation of diets that contain lower total protein than with other oilseed meals, thereby reducing the amount of nitrogen to be excreted by the animal and reducing the nitrogen load on the environment. Extrusion of soybean meal does not appear to affect the ileal or total tract apparent digestibilities of DM, CP, fibre fractions or DE, or AA availabilities for young pigs.

Soybean meal is generally low in minerals and vitamins (except choline and folic acid). Liener (2000) estimated that two-thirds of the phosphorus in soybeans is bound as phytate and is mostly unavailable to animals. This compound also chelates mineral elements including calcium, magnesium, potassium, iron and zinc, rendering them unavailable to the pig. Therefore diets based on soybean meal have to contain adequate amounts of these trace minerals. This fact has been known for some time, Smith *et al.* (1962) reporting that maize/soybean meal diets had to be supplemented with zinc to avoid a parakeratosis condition in growing pigs. Another approach to the phytate problem is to add phytase – an enzyme that degrades phytic acid – to the feed, to release phytin-bound phosphorus. A benefit of this approach is that less phosphorus needs to be added to the diet, reducing excess phosphorus loading into the environment.

ANTI-NUTRITIONAL FACTORS Natural anti-nutritional factors are found in all oilseed proteins (Chiba, 2001). Among those in raw soybeans are protease inhibitors. These are known as the Kunitz inhibitor and the Bowman–Birk inhibitor which are active against trypsin, while the latter is also active against chymotrypsin (Liener, 1994). These protease inhibitors interfere with the digestion of proteins, resulting in decreased animal growth. They are inactivated when the beans are toasted or heated during processing. However, care has to be taken that the ingredient is not overheated. When proteins are heat-treated at too high a temperature the bioavailability of protein and AA may be reduced because of a substantial loss of available lysine as a result of the browning or Maillard reaction. The browning involves a reaction between the free amino group on the side-chain of lysine with a reducing sugar to form brown, indigestible polymers.

Lectins (hemagglutinins) in raw soybeans can inhibit growth and cause death in animals. They are proteins that bind to carbohydrate-containing molecules and cause blood clotting. Fortunately lectins are degraded rapidly by heating.

Soybeans also contain growth inhibitors that are not easily deactivated by heat treatment. Certain oligosaccharides in soybean meal are indigestible and can cause excessive fermentation in the hindgut of young pigs (Cromwell, 1998). Li *et al.* (1990) reported that soybean meal caused transient hypersensitivity, which seemed to be caused by glycinin and β-conglycinin (Li *et al.*, 1991). These factors are reduced by extrusion of the beans and the reduction in antigenic activity appeared to have beneficial effects on intestinal morphology, immunology and growth performance of weanling pigs (Li *et al.*, 1991).

Soybeans have been reported to contain several antigenic proteins, which can cause adverse reactions in the gastrointestinal tract. The allergenic effect is attributed to the globulin fraction of soybean proteins. However they do not appear to cause problems in pigs.

PIG DIETS An appropriate combination of soybean meal and maize (or most other cereal grains) provides an excellent dietary AA pattern for all classes of pig (Seerley, 1991; Chiba, 2001). Conventional soybean meal is one of the most consistent feed ingredients available to the feed manufacturer, with the nutrient composition and physical characteristics varying very little between sources. Suppliers of organic soybean meal need to adopt similar quality control measures to ensure similar consistency in composition.

Proper processing of soybeans requires precise control of moisture content, temperature and processing time. Adequate moisture during processing ensures destruction of the anti-nutritional factors. Both over- and under-toasting of soybean meal can result in a meal of lower nutritional quality. Under-heating produces incomplete inactivation of the anti-nutritional factors and over-toasting can reduce AA availability.

The industry monitors soybean meal quality by using urease activity to detect underheating and potassium hydroxide solubility to detect overheating. The urease assay measures urease activity based on the pH increase caused by ammonia release from the action of the urease enzyme. Destruction of the urease activity is correlated with destruction of trypsin inhibitors and other anti-nutritional factors. To measure KOH solubility, soy products are mixed with 0.2% KOH and the amount of nitrogen solubilized is measured. The amount of nitrogen solubilized decreases as the heating time increases, indicating decreased AA availability.

Full-fat soybeans

Correctly processed whole (full-fat) soybeans can be used in pig diets. Extruded soybeans are whole soybeans which have been exposed to a dry or wet (steam) friction heat treatment without removing any of the component parts. Roasted soybeans are whole soybeans which have been exposed to a heat or micronized treatment without removing any of the component parts. Since soybeans contain a high-quality protein and are a rich source of oil, they have the ability to provide major amounts of protein and energy in the diet. Use of full-fat beans is a good way of increasing the energy level of the diet, particularly when they are combined with low-energy ingredients. Also, this is an easier way to blend fat into a diet than by the addition of liquid fat. Several reports show that properly processed whole soybeans can be used effectively in pig diets. Pigs appear to grow as well on pelleted diets containing extruded or roasted soybeans as on diets of similar nutrient content and based on soybean meal and soybean oil. The improved performance from roasting or extruding can be attributed to an increase in fat digestibility (the oil vesicles being ruptured to allow the oil to be more available for digestion) and to an increased nutrient density in the diet. Properly cooked soybeans can be used to replace soybean meal in grower-finisher and breeder diets (Danielson and Crenshaw, 1991; Seerley, 1991), and they may improve the performance of growing pigs and reproductive performance of sows due to additional dietary lipids. However, whole soybeans may have adverse effects on the carcass fat of growing pigs. A standard recommendation is that the soybean product should be limited to supplying a dietary addition of 20 g soybean oil/kg in order to ensure an acceptable carcass fat quality and good pellet quality. This may require that the incorporation rate of soybeans in the feed of finishing pigs should not exceed 100 g/kg. Cooked soybeans are particularly useful in lactation diets when intake is low and pig pre-weaning survival rate is higher than normal, indicating reduced milk output.

Including full-fat soybeans in pig diets reduces aerial dust levels, and is likely to benefit the health of animals and workers in buildings. Because of possible rancidity problems, diets based on full-fat soybeans should be used immediately and not stored. Otherwise, an approved antioxidant should be added to the diet.

Soy protein isolates

Soybean protein concentrate (or Soy protein concentrate IFN 5-08-038) is the product obtained by removing most of the oil and water-soluble non-protein constituents from selected, sound, cleaned, dehulled soybeans. The traded product in North America contains not less than 650 g CP/kg on a moisture-free basis. Soybean protein isolate (or Soy protein isolate IFN 5-24-811) is the dried product obtained by removing most of the non-protein constituents from selected, sound, cleaned, dehulled soybeans. The traded product contains not less than 900 g CP/kg on a moisture-free basis. Both soy protein concentrate and soy protein isolate can be used successfully in weanling pig diets as a replacement for dried skimmed milk (Sohn *et al.*, 1994).

Sunflower seeds and meal (*Helianthus annuus*)

Sunflower is an oilseed crop of considerable potential for organic pig production since it grows in many parts of the world. The main producers are Europe (France, Russia, Romania and Ukraine), South America, China and India. Sunflower is grown for oil production, leaving the extracted meal available for animal feeding. Sunflower oil is highly valued for its high PUFA content and stability at high temperatures (Chiba, 2001). Sunflower seed surplus to processing needs and seed unsuitable for oil production may also be available for feed use. On-farm processing of sunflower seed is being done in countries such as Austria (Zettl *et al.*, 1993).

NUTRITIONAL FEATURES The nutrient content of sunflower seeds and meals has been reviewed by Chiba (2001). Per kg, the seeds contain approximately 380 g oil, 170 g CP and 159 g CF and are a good source of dietary lipids for pigs. The protein is very deficient in lysine for pig feeding.

Sunflower meal is produced by extraction of the oil from sunflower seeds. The nutrient composition of the meal varies considerably, depending on the quality of the seed, method of extraction and content of hulls. The CF content of whole (hulled) sunflower meal is around 300 g/kg and with a complete decortication (hull removal) the fibre content is around 120 g/kg. Sunflower meal is lower in lysine and higher in sulphur-containing AA than soybean meal. However its DE value is considerably lower than that of soybean meal. Calcium and phosphorus levels compare favourably with those of other plant protein sources. Sunflower meal tends to be lower in trace elements compared with soybean meal. In general, sunflower meal is high in B vitamins and β-carotene. Because of its high fibre content it should be used in limited quantities in pig diets. Sunflower meal containing high levels of oil can produce soft backfat because of the unsaturated fatty acid content.

ANTI-NUTRITIONAL FACTORS In contrast to other major oilseeds and oilseed meals, sunflower seeds and meals appear to be relatively free of anti-nutritional factors (Chiba, 2001) and the oil is utilized well by pigs.

PIG DIETS Performance of piglets and growing-finishing pigs was not affected when soybean meal was replaced by twice-decorticated sunflower meal (Cortamira *et al.*, 2000). However, the substitution required supplementation with pure lysine and vegetable oil to match the nutrients contained in a soybean meal-based diet. In spite of this finding, most studies report decreased growth performance when sunflower meal completely replaces soybean meal in diets for growing-finishing pigs and that lysine supplementation alleviates, but does not correct, the reduction (Aherne and Kennelly, 1985; Wetscherek *et al.*, 1993; Shelton *et al.*, 2001). A high level of sunflower meal is required to replace all of the soybean meal in diets based on maize for growing-finishing pigs; the study by Shelton *et al.* (2001) involved 587 g sunflower meal/kg. Other work (Zettl *et al.*, 1993) showed similar growth performance in pigs from about 35 to 105 kg live weight when fed diets based on soybean meal or 100 g sunflower meal/kg plus 140 g pea meal/kg to partially replace soybean meal. Digestibility of organic matter and CP decreased with sunflower meal at 200 g/kg. The proportions of linoleic and arachidonic acids in backfat increased when sunflower meal was included in the diet. These findings are the basis for a general recommendation that sunflower meal can be used to replace up to 25% of the protein in the diet for growing-finishing pigs. The digestible lysine content needs to be maintained when sunflower meal is included in diets for growing pigs. It is unlikely that higher levels of sunflower meal can be used in organic diets since supplements of pure lysine are not acceptable. Because the lysine requirements of gestating females and adult boars are lower, sunflower meal can be used as the only source of protein in their diet (Chiba, 2001), provided the diet contains sufficient other sources of digestible lysine. For lactation diets, sunflower meal can be used in combination with other protein sources high in lysine.

Chiba (2001) reviewed the use of sunflower seed in pig diets. Because of its high oil content, sunflower seed provides a convenient method of providing additional energy to pig diets and the oil in sunflower seed appears to be utilized well by pigs (Adams and Jensen, 1985). However Fitzner *et al.* (1989) concluded that the inclusion of sunflower seeds should be limited to 150 g/kg diet for weanling pigs. As the content of sunflower seed increased from 0 to 600 g/kg diet for grower pigs, feed intake decreased and feed efficiency increased linearly (Laudert and Allee, 1975). For grower-finisher pigs, 100 g sunflower seed/kg increased weight gain in one trial but reduced it slightly in another (Hartman *et al.*, 1985). Improved protein digestibility with the addition of sunflower seeds (Noland *et al.*, 1980; Marchello *et al.*, 1984) may partially explain the beneficial effects of sunflower seeds on the growth performance of pigs. On the other hand, inclusion of sunflower seeds at 250 and 500 g/kg reduced weight gain in finisher pigs (Laudert and Allee, 1975). In addition, adverse effects of sunflower seeds on carcass quality have been reported, and it has been recommended that grower-finisher diets should not contain more than 100 g (Hartman *et al.*, 1985) or 130 g (Marchello *et al.*, 1984) sunflower seeds per kg. A general recommendation is, therefore, that sunflower seeds should not be included in starter, grower or finisher diets at levels more than 100–150 g/kg diet.

Research on the use of sunflower seeds in breeding stock is limited (Wahlstrom, 1990). Percentage of milk fat increased linearly as dietary sunflower increased from 0 to 500 g/kg but pig weaning weight or percentage survival was not affected (Kepler *et al.*, 1982). Because of reduced feed intake in sows fed diets containing 500 g sunflower seeds/kg, Kepler *et al.* (1982) concluded that sunflower seeds should be limited to 250 g/kg in sow diets.

Fat sources

Fats are often used as dietary supplements to provide additional energy. They have other benefits such as increasing palatability of the diet and reducing dustiness. Animal fats are not permitted in organic diets but the plant oils listed in Table 4.2 should be acceptable. These oils are concentrated sources of energy, providing about 2.25

Table 4.2. Energy value of common oil supplements as dietary sources of energy.

Ingredient	International Feed Number	Digestible energy (kcal/kg)
Canola oil	4-20-834	8760
Cottonseed oil	4-20-836	8605
Maize oil	4-07-882	8755
Safflower oil	4-14-505	8760
Soybean oil	4-07-983	8750
Sunflower oil	4-20-833	8760

times as much energy as starch on an equivalent weight basis. This makes them very useful ingredients when the energy level of the diet needs to be increased. Normally low levels of oil should be added to diets; otherwise the diets become soft, difficult to pellet and subject to rancidity. It may be especially useful to supplement the diet of sows prior to farrowing, to help increase baby pig survival. All of the oils are unstable and subject to rancidity, therefore they should be used rapidly after delivery and not stored for extended periods. Purchased oils may be stabilized by the addition of an antioxidant which should meet organic standards.

Legume Seeds, Their Products and By-products

Faba (*Vicia faba* L.)

The faba bean, also known as the field bean, horse bean and broad bean, is an annual legume that grows well in cool climates. It is well established as a feedstuff for horses and ruminants and is now receiving more attention as a feedstuff for pigs, particularly in Europe because of the deficit in protein production. At the current time, the EU uses over 20 million tonnes of protein feeds annually, but produces only 6 million tonnes. The most suitable expansion in locally produced protein feedstuffs may be from crops of the legume family (beans, peas, lupins and soybeans). Field beans grow well in regions with mild winters and adequate summer rainfall, and store well for use on-farm.

Fig. 4.2. Faba beans: an example of protein crop that can be grown for self-sufficiency on organic pig farms.

NUTRITIONAL FEATURES Faba beans (field beans) are often regarded nutritionally as high-protein cereal grains. They contain about 240–300 g CP/kg, the protein being high in lysine and (like most legume seeds) low in sulphur-containing AA. The DE level is similar to that of barley or wheat. The CF content is around 80 g/kg, air-dry basis. The oil content of the bean is relatively low (10 g/kg DM), with a high proportion of linoleic and linolenic acids. This makes the beans very susceptible to rancidity if stored for more than about a week after grinding. When fresh they are very palatable.

A large study in Poland found that the average CP value was 235.2 g/kg in organic faba beans compared with 247.5 in conventional field beans (Grela and Semeniuk, 2008). The corresponding values for CF and ME were 79.1 and 72.6 g/kg, and 14.1 and 14.4 MJ/kg DM.

As with the main cereals, faba beans are a relatively poor source of calcium and are low in iron and manganese. The phosphorus content is higher than in canola. Faba beans contain lower levels of biotin, choline, niacin, pantothenic acid and riboflavin, but a higher level of thiamin, than soybean meal or canola meal.

ANTI-NUTRITIONAL FACTORS Faba beans contain several anti-nutritional factors such as tannins, protease inhibitors and lectins. The levels of trypsin inhibitor and lectin activities are low compared with other legume seeds (Thacker, 1990c; Vidal-Valverde *et al.*,

1997) and do not pose problems in pig diets when faba beans are incorporated into diets at the levels shown below. The factor of most concern for pigs is the tannins fraction (Jansman *et al.*, 1989; Marquardt, 1989; Garrido *et al.*, 1991; van der Poel *et al.*, 1991). Tannins in whole faba beans are associated with the seed coat (testa), and the tannin content is related to the colour of the seed coat (and flowers). Tannins are lower in white-seed than in the coloured-seed varieties (Reddy *et al.*, 1985; van der Poel *et al.*, 1991, 1992). Grosjean *et al.* (2001) conducted a digestibility trial with ten batches of French faba beans to determine the effects of tannins, vicine and convicine, on the nutritional value. Apparent protein digestibility of faba beans without tannins was higher than with tannins (88.4 versus 80.0%). Energy digestibility and DE were also higher (90.0 versus 78.7% and 16.7 versus 14.7 MJ/kg DM, respectively). The results were explained mainly by the effect of tannins and to a lesser extent by the effect of fibre, because tannin-free faba beans have lower fibre levels than tannin-containing faba beans. Vicine and convicine levels had little effect on protein and energy digestibility.

The nutritional value of diets containing faba beans (about 300 g/kg) with various levels of condensed tannins (proanthocyanidins) was studied by Flis *et al.* (1999). Polish Large White × Duroc pigs were fed, over the weight range 25–63 kg, four diets: HT containing high-tannin faba (with 1 g phenols/kg and 0.6 g proanthocyanidins/kg); LT with low-tannin field beans; DHT with dehulled high-tannin field beans; and DHTF with dehulled high-tannin field beans and added white-flowering pea hull fibre. The proanthocyanidin content of the HT, LT, DHT and DHTF diets was 591, 8, 70 and 70 mg/kg, respectively. The digestibility of energy, but not protein, was higher in the LT and DHT diets than in the HT diet. Daily nitrogen retention and utilization did not differ between groups. Daily body weight gains (684–693 g) and feed conversion ratio (3.02–3.07 kg/kg) also did not differ. The results showed that the high-tannin diet had a slightly lower nutritional value in terms of ME and digestible protein. However, it did not result in a reduced growth rate in comparison with animals fed the low-tannin or dehulled high-tannin diets.

Improvements in growth performance have been noted when faba beans were roasted or extruded before feeding, possibly due to an improvement in AA digestibility or destruction of anti-nutritional factors (Pond and Maner, 1984). The effects of including raw, toasted or extruded faba beans at 210 g/kg in diets based on ground barley, maize and soybeans were studied in crossbred pigs from 30 to 100 kg live weight (Wetscherek *et al.*, 1995). Body weight gain and carcass quality were not affected by type of faba bean processing.

Research was conducted on a zero-tannin faba bean by Zijlstra *et al.* (2004b). Growing pigs were fed either a soybean- or the faba bean-based diet from 30 to 115 kg. Results showed that voluntary feed intake did not differ between diets, nor did carcass quality. These researchers concluded that zero-tannin faba beans have a desirable nutrient profile and can be used successfully in diets for growing-finishing pigs at an inclusion rate up to 300 g/kg as a replacement for soybean meal.

PIG DIETS For use in pig diets the beans are usually ground to pass through a 3 mm screen. Kasprowicz *et al.* (2005) investigated the effects of dietary inclusion of faba bean seeds cv. Kodam, as a substitute for soybean meal on body weight gain and feed utilization of young pigs weighing about 14 kg. The diets contained soybean meal or 25, 50 or 75% of the soy protein replaced by faba beans. The experiment was terminated when the animals reached 36 kg body weight. Average daily gain of the animals in the control group was 586 g, and feed:gain ratio was 2.59 kg/kg. In the experimental groups, the corresponding values were 577 g and 2.35 kg/kg, 629 g and 2.28 kg/kg, and 637 g and 2.17 kg/kg, respectively. Brand *et al.* (1995) investigated the value of faba beans as a partial replacement for soybean oilcake in diets for growing-finishing pigs in a South African study. From 30 to 90 kg live weight the pigs were fed diets containing (per kg) 83 g fishmeal, 200 g faba beans or 200 g low-alkaloid lupin meal. Daily feed intake and live-weight gain of pigs fed the lupin diet

(2489 g and 768 g/day, respectively) were lower than those of pigs fed the faba bean (2637 g and 857 g/day, respectively) and fishmeal (2668 g and 869 g/day, respectively) diets. Pigs fed the lupin diet had a poorer feed conversion ratio (3.27) than those on the faba bean and fishmeal diets (3.03 and 3.12, respectively). Dietary treatment had no effect on carcass dressing percentage (mean 78%), eye muscle area (41.3 cm^2) or P2 backfat thickness (mean 16 mm). These results confirm earlier findings that faba beans can be used to replace part of the soybean meal in diets for growing-finishing pigs.

No recent studies with breeding sows have been reported. Reports from the 1970s showed that the inclusion of field beans at 210 g/kg as a replacement for soybean meal did not affect reproductive performance (Pond and Maner, 1984). However some Danish trials (Pond and Maner, 1984) reported that an inclusion rate of 170 g faba beans/kg resulted in reductions in litter size and piglet weight at birth and weaning, and in milk production by the sow. These findings have not been confirmed by more recent studies.

On the basis of the available data, the suggested maximal rates of inclusion of faba beans in pig diets are 100 g/kg for sows and 200 g/kg for weaner-finishers.

Field peas

Field peas are grown primarily for human consumption, but they are now used widely in pig feeding also, especially in Canada, the northern USA and Australia. Some producers grow peas in conjunction with barley, as these two ingredients can be successfully incorporated into a pig feeding programme. Peas are a good cool-season alternative crop for regions not suited to growing soybeans. They may be particularly well suited for early planting on soils that lack water-holding capacity and they mature early. There are green and yellow varieties, which are similar in nutrient content. Those grown in North America and Europe, both green and yellow, are derived from white-flowered varieties. Brown peas are derived from coloured-flower varieties. They have higher tannin levels, lower starch, higher protein and higher fibre contents than green and yellow peas. These varietal differences account for much of the reported variation in nutrient content.

Pea protein concentrate from starch production may also be available as a feed ingredient.

NUTRITIONAL FEATURES Peas are similar in energy content to high-energy grains such as maize and wheat, with about 3485 kcal DE/kg, but they have a higher CP content (about 230 g/kg) than grains (Gatel, 1994). Thus they are regarded primarily as a protein source.

Jacob (2007) reported a lower CP value in organic peas (216.1 g/kg) than in peas grown conventionally (238 g/kg). A similar finding was reported in a large study in Poland, the average CP value being 215.7 g/kg in organic peas compared with 221.3 in conventional peas (Grela and Semeniuk, 2008). The corresponding values for CF and ME were 68.1 and 64.8 g/kg; and 15.4 and 15.8 MJ/kg DM. Pea protein is particularly rich in lysine, but relatively deficient in tryptophan and sulphur-containing AA. The DE content is close to that of soybean meal and the NE value is very high compared with other protein feedstuffs. This is due to the very high starch level, which is highly digestible. The starch type is similar to that in cereal grains. As with most crops, environmental conditions can affect the protein content. Hot and dry growing conditions tend to increase CP content. Starch content has been found to be correlated inversely with CP content. At 230 g CP/kg the starch content is approximately 460 g/kg; therefore a correction for starch and energy content should be made if the peas differ significantly from 230 g CP/kg. AA content is correlated with CP content and prediction equations have been produced.

Ether extract (oil content) of peas is around 14 g/kg. The fatty acid profile of the oil in peas is similar to that of cereal grains, being primarily polyunsaturated. The proportions of major unsaturated fatty acids are linoleic (50%), oleic (20%) and linolenic (12%) (Carrouée and Gatel, 1995).

Feed peas, like cereal grains, are low in calcium but contain a slightly higher level of phosphorus (about 4 g/kg). They contain about 12 g phytate/kg, similar to soybeans (Reddy *et al.*, 1982). The levels of trace minerals and vitamins in peas are similar to those found in cereal grains.

The fibre in peas occurs mainly in the cell walls. Appreciable levels of galactans are found in peas. Peas contain approximately 50 g oligosaccharides/kg, made up mainly of sucrose, stachyose, verbascose and raffinose. Compared with some other pulses such as lupins and beans, the levels of gas-producing oligosaccharides are fairly low and not enough to create sufficient gas production in the hindgut to result in flatulence.

ANTI-NUTRITIONAL FACTORS The factors that may be present in peas include: amylase, trypsin and chymotrypsin inhibitors; tannins (proanthocyanidins); phytate; saponins; hemagglutinins (lectins) and oligosaccharides. However, they generally do not present any problems in feeding peas to pigs, except that it is advisable to restrict the level of peas in diets for young pigs. Otherwise few special precautions are required. The levels of trypsin inhibitor in field peas are usually low at less than 4 TIU/mg (Liener, 1983; Sauer and Jaikaran, 1994). Problems of reduced protein digestibility may occur with trypsin inhibitor activity (TIA) higher than 6 TIU/mg (Grosjean and Gatel, 1989). European research has shown that spring pea varieties have higher levels of DE and lower levels of anti-nutritional factors for pigs than winter pea varieties (Grosjean and Gatel, 1989). Therefore spring varieties are preferred for pig feeding. Some research has shown that smooth peas have higher TIA than wrinkled varieties (Valdebouze *et al.*, 1980), but that TIA was significantly affected also by cultivar and environmental conditions (Wang *et al.*, 1998). Grosjean *et al.* (2000) demonstrated an inverse relationship between the level of trypsin inhibitor and ileal AA digestibility in pigs. They found that standard ileal AA digestibility decreased by over 0.2% for each unit increase in TIA.

Tannins are polyphenolic compounds that may inhibit the activity of several digestive enzymes. They are found in the hull, particularly in brown-seeded cultivars, but are unlikely to pose a problem if brown-seeded cultivars are avoided. Most of the field peas grown in Europe and Canada have zero tannin content.

Saponins and other anti-nutritional factors that occur in peas appear to have insignificant effects in pigs.

PIG DIETS Results show that peas can be used effectively in diets for weaned pigs. They should be ground or pelleted with other feedstuffs when included in pig diets. Trials by Kehoe *et al.* (1991) with pigs weaned at 21 and 28 days and fed starter diets containing peas at 200 g/kg in place of soybean meal showed no adverse effect on rate of gain or feed efficiency. An antigenic response to high levels of legume proteins can occur with very young animals but does not appear to be a practical problem with older pigs. From these and other trials it can be concluded that, for pigs weaned at 6 weeks of age, peas can be included in the diet at levels up to 200 g/kg.

Peas have been shown to be well accepted as a dietary component by older pigs. In trials with pigs fed from 23 kg live weight to 100 kg market weight by Bell and Keith (1990), feeding diets containing peas at up to 568 g/kg resulted in no adverse effect on feed intake compared with soybean-based diets. Similar responses to peas have been obtained in Europe, provided the diets were formulated appropriately (Gatel and Grosjean, 1990). Yacentiuk (1994) found that peas could be used effectively as the sole supplementary protein source if diets were balanced to appropriate nutrient levels. No differences in carcass quality or sensory characteristics of the meat have been reported in pigs fed pea-based diets (Bell and Keith, 1990; Cote and Racz, 1991; Castell and Cliplef, 1993). Peas have given good results in both pelleted diets and mash diets for growing-finishing pigs. One benefit of including peas in pelleted diets is an improvement in pellet quality, due in part to gelatinization of the starch. Inclusion of peas at 100–150 g/kg diet has been shown to avoid the need for pellet binders.

The high protein quality and high DE of peas make them particularly useful in lactating sow diets. Research in Europe by Gatel *et al.* (1987) showed no differences in wheat/maize (50:50)-based dry sow and nursing sow diets when peas were substituted for all the supplemental protein provided by soybean meal. Pigs weaned per litter were 11.05 and 11.04 with soybean and pea diets, respectively. Piglet birth weights were 1.28 and 1.29 kg, lactation growth rate was 210 and 216 g/day and pigs weaned per sow per year were 23.2 and 23.4, respectively, with soybean meal and pea diets. Jacyno *et al.* (2000) showed no effect on semen quality of boars fed diets containing peas.

Lentils (*Lens culinaris*)

Lentils are a legume seed, grown primarily as a human food crop. Surplus and cull lentils may be available economically for inclusion in pig diets. The main producing countries are India, Turkey and Canada. Canadian cultivars are mostly green with yellow cotyledons, unlike the red-cotyledon types grown in other countries.

NUTRITIONAL FEATURES Castell (1990) reviewed findings on the nutrient content of lentils and concluded that they are similar to peas in nutrient content. However the CP content may be slightly higher than in field peas. As with other legume seeds, lentils have a low content of sulphur-containing AA. As a result lentils need to be combined with other protein sources in the diet to provide a satisfactory AA profile. The oil content of lentils is low at around 20 g/kg, with linoleic and linolenic accounting for 44 and 12%, respectively, of the total fatty acids (Castell, 1990). The level of lipoxygenase present in the seed suggests the potential for rapid development of rancidity after grinding of lentil seeds (Castell, 1990).

ANTI-NUTRITIONAL FACTORS In common with many other legume seeds, raw lentils contain some undesirable constituents, although the levels of these are not likely to be of concern in swine feeding. Weder (1981) reported the presence of several protease inhibitors in lentils. Marquardt and Bell (1988) also identified lectins (hemagglutinins), phytic acid, saponins and tannins as potential problems but could find no evidence that these had adversely affected performance of pigs fed lentils. It is known that cooking improves the nutritive value of lentils for humans but the effects of consumption of raw lentils by non-ruminants have not been well documented (Castell, 1990).

PIG DIETS There is a paucity of published information regarding the feeding value of lentils for swine but Canadian studies provide some information (Castell, 1990). Bell and Keith (1986) conducted studies with growing-finishing pigs to determine the digestibility and utilization of frost-and blight-damaged lentils. Dietary levels up to 300 g/kg did not adversely affect growth performance, though the digestibility of energy was higher than that for CP. Subsequent studies (Castell and Cliplef, 1988), involving rates of inclusion up to 400 g/kg in isonitrogenous diets fed to growing-finishing pigs, suggested the optimal rate was in the range of 100–200 g/kg. Higher levels appeared to result in a reduction in meat quality, as judged by a trained taste panel. A later study (Castell, 1990) showed that the addition of 1 g methionine/kg to a diet containing 400 g lentils/kg improved the performance and carcass characteristics of pigs to a level similar to that of pigs receiving an isonitrogenous diet based on barley and soybean meal.

Lupins

Lupins are becoming of increasing importance as a feed ingredient, especially in Australia, which is also an exporter of this product. Benefits of this crop for the organic producer are that the plant is a nitrogen-fixing legume and, like peas, can be grown and utilized on-farm with minimal processing. Another advantage of lupins is that the seed stores well. The shortage of organic protein feedstuffs in Europe has stimulated interest in lupins as an alternative protein source.

The development of low-alkaloid (sweet) cultivars in Germany in the 1920s allowed the seed to be used as animal feed. Prior to that time the crop was unsuitable for animal feeding because of a high content of toxic alkaloids in the seed. In Australia, where much of the research on lupins as a feedstuff for pigs has been done, the main species of lupins used in pig diets are *Lupinus angustifolius* and *Lupinus luteus*. *Lupinus albus* is reported as not currently recommended for use in conventional pig diets in Australia because of a reduction in growth rate (Edwards and van Barneveld, 1998). *L. luteus* (yellow lupin) is regarded as having significant potential as a feedstuff in Australia. This lupin is native to Portugal, western Spain and the wetter parts of Morocco and Algeria.

NUTRITIONAL FEATURES The CP content of *L. angustifolius* has been reported as ranging from 272 to 372 g/kg and of *L. albus* from 291 to 403 g/kg (air-dry basis) (van Barneveld, 1999b). Recent selections of *L. luteus* have been found to have a higher CP content (380 g/kg, air-DM basis) than either *L. angustifolius* (320 g/kg, air-DM basis) or *L. albus* (360 g/kg, air-DM basis) (Petterson *et al.*, 1997) and to yield better than *L. angustifolius* on acid soils of low fertility (Mullan *et al.*, 1997). Lupin proteins are mainly composed of globulins, with this fraction being higher in lupins and soybeans than most other legumes. In contrast, faba beans and peas have legumin as the major protein. Lupin protein was reported to be limiting in methionine (0.59–0.87 g/16 g N) and lysine (4.21–5.21 g/16 g N) for pigs (Gdala *et al.*, 1996). Tryptophan ranged from 0.7 to 0.9 g/16 g N. Recently introduced species such as *L. luteus* have been reported to have lysine, threonine, cystine and methionine concentrations that are significantly higher than the more traditional varieties (Mullan *et al.*, 1997). These species show great potential as livestock feeds and have protein levels comparable to soybean meal if dehulled (van Barneveld, 1999b). The availability of AA in lupins is high, similar to that of soybeans (Mullan, 2000). The ileal digestible AA coefficients for lupins are 0.86 for lysine and 0.8–0.9 for other AA (Ajinomoto, 2006). For peas the corresponding coefficients are 0.83 and 0.72–0.8.

The CF content of lupins was reported to be 130–150 g/kg in *L. luteus* and *L. angustifolius* and slightly lower in *L. albus* (Gdala *et al.*, 1996). The highest NDF (227 g/kg) and ADF (186 g/kg) contents were found for the *L. luteus* variety ‘Amulet’, while the lowest values (201 and 146 g/kg, respectively) were found in *L. luteus* ‘Cybis’ and *L. albus* ‘Hetman’. Mullan (2000) determined the DE content of *L. luteus* to be 16.41 MJ/kg (DM basis), similar to the value for *L. albus* determined by King (1997). However, the accuracy of DE estimates is questionable because of the carbohydrate chemistry of lupins. This is different from that in most legumes, with negligible levels of starch and high levels of soluble and insoluble NSP and oligosaccharides (up to 500 g/kg seed) (van Barneveld, 1999b). Lupins contain pectic substances with the major polysaccharide being galactans. The CF component contains more hemicellulose than in other legumes such as peas and faba beans, which have cellulose as the major component. The lignin content of lupins is also low, comparable with that in peas. These features influence the utilization of energy from lupins (van Barneveld, 1999b). The high content of galactans and hemicellulose results in a higher proportion of the carbohydrate being fermented in the large intestine. As a result the DE value often significantly overestimates the NE content (Taverner *et al.*, 1983). In pigs, van Barneveld *et al.* (1995) demonstrated that as the level of lupins increased in the diet DE did not change, but the proportion of energy digested by the end of the small intestine decreased significantly. These findings may account for the high degree of variation that has previously been observed in the DE content of ground whole lupin seed and lupin kernels (van Barneveld, 1999b). Wigan *et al.* (1994) reported a range of 12.3–15.3 MJ/kg for lupinseed meal and 15.4–16.6 MJ/kg for lupin kernels. Thus, the high levels of NSP in lupins make it difficult to optimize the efficiency of lupin use in diets for growing pigs unless a net energy measure is used (van Barneveld, 1999b). Despite these findings, Noblet *et al.* (1998) suggested that lupins are an excellent energy source for pigs. The sow has a high capacity for hindgut fermentation of lupin kernel and hulls and consequently can extract a significant amount of energy from lupins when they are included in diets. Noblet (1997) reported a higher energy concentration in lupin hulls for sows (14.0 MJ ME/kg, DM basis) than for growing pigs (7.4 MJ ME/kg). On the basis of these findings van Barneveld (1999b) recommended the need for care when feeding lupins to sows. High fermentation levels were accompanied by high levels of gas production; when lupins are included in sow diets at levels above 200 g/kg diet the excess gas production could compromise sow health.

The crude fat content of lupins appears to vary within and between species. The range of values for common species grown in Australia has been reported as 49.4–130.0 g/kg (van Barneveld, 1999b), the main fatty acids being linoleic (483 g/kg), oleic (312 g/kg), palmitic (76 g/kg) and linolenic (54 g/kg). Petterson (1998) reported that extracts of *L. angustifolius* oil were stable for 3 months at 51°C, indicating a high level of antioxidant activity in this material and helping to explain the good storage characteristics of lupins. Gdala *et al.* (1996) reported that the oil content in *L. albus* was almost twice as high (104 g/kg) as in *L. angustifolius* and more than twice as high as in *L. luteus*. Lupins are low in most minerals, with the exception of manganese. *L. albus* is known to accumulate manganese and it has been suggested that high manganese content might be the explanation for a reduced voluntary feed intake with diets containing this species of lupin. However, excessive manganese levels in lupins do not appear to be the cause of reduced feed intake.

ANTI-NUTRITIONAL FACTORS Pigs are known to be sensitive to alkaloids in lupins, but the average alkaloid content of cultivars of *L. angustifolius* and *L. albus* now used is generally low (< 0.04 g/kg; van Barneveld, 1999b). The total alkaloid content of lupin seeds ranged from 0.3 g/kg in *L. angustifolius* to 0.6 g/kg in *L. albus*. The major metabolic effect of lupin alkaloids and their metabolites is neural inhibition, but they can also inhibit circulation, digestion, reproduction, respiration and the immune system (Hill and Pastuszewska, 1993). Several cases of feed rejection and vomiting were found to be caused by diets containing *L. angustifolius* with unusually high contents of alkaloid (van Barneveld, 1999b). Therefore it is advisable to monitor alkaloid levels in lupins as part of the quality programme. The alkaloid content of *L. albus* appears to be lower and less variable than that of *L. angustifolius* cultivars; therefore van Barneveld (1999b) concluded that the total alkaloid content was not the reason for the lower acceptability of *L. albus* by pigs. Cuadrado *et al.* (1995) reported levels of total saponins in *L. albus* of less than 12 mg/kg and in *L. luteus* of 55 mg/kg, leading these authors to conclude that it was unlikely that saponins were responsible for reduced feed intakes of diets containing *L. albus*. The levels of tannins in *L. angustifolius* are considered low enough for this not to be a problem in pig diets (van Barneveld, 1999b). Data on the tannin levels in *L. albus* and *L. luteus* appear to be more limited. Low-alkaloid lupins appear also to contain zero or very low levels of trypsin inhibitors and hemagglutinins (van Barneveld, 1999b).

PIG DIETS Ground lupin seed from *L. angustifolius* can be included in pig diets at high levels without affecting feed intake and subsequent performance (Edwards and van Barneveld, 1998). These authors recommended maximum dietary inclusion levels of 200–250 g/kg for growing pigs of 20 to 50 kg live weight, 300–350 g/kg for finishing pigs of 50 to 100 kg live weight, and 200 g/kg for dry-sow and lactation diets.

Kelly *et al.* (1990) reported that inclusion of *L. albus* cv. Ultra in pig diets at levels above 100 g/kg diet significantly reduced the growth rate of pigs weighing 30–57 kg, while finishing pigs could tolerate dietary inclusion levels of up to 200 g/kg diet. Reduction in growth performance was attributed to a reduction in feed intake at the higher inclusion levels. Reduction in feed intake has also been reported with other *L. albus* cultivars (van Barneveld, 1999b).

Similar results with *L. albus* cv. Ultra were reported by Donovan *et al.* (1993) for growing pigs fed diets containing up to 190 g/kg diet as a replacement for soybean meal. No reduction in feed intake was observed in finisher pigs. Reductions in feed intake of growing pigs has been observed with *L. luteus* cultivars (Jacyno *et al*., 1992; Mullan *et al*., 1997) and a maximum dietary inclusion level of 120–180 g/kg diet was suggested for animals between 20 and 55 kg live weight. Gdala *et al*. (1996) conducted a study on nitrogen balance and growth performance of young pigs (12–14 kg initial body weight) fed diets containing meals from *L. luteus*, *L. albus* and *L. angustifolius* (all grown in Poland) and a commercial batch of lupin seed from Australia. The inclusion level ranged from 310 to 410 g/kg. Digestibility of DM (0.91) and CP (0.90) in *L. luteus* diets was as high as in the soybean diet. The lowest digestibility of DM (0.86) and CP (0.83) was with the diet containing *L. albus*. Utilization of the apparently digested nitrogen (nitrogen retained as a proportion of nitrogen digested) was highest in the soybean and *L. angustifolius* groups. The growth performance of pigs given diets with *L. luteus*, *L. angustifolius* and Australian lupin seed was similar to that of pigs given the soybean diet, but pigs given the *L. albus* diet had a higher feed conversion ratio. The results suggested that *L. albus* was a less suitable supplementary protein source for young pigs than soybean meal, possibly due to its content of 0.2 g alkaloids/kg. This conclusion is in agreement with the findings of Buraczewska *et al*. (1993) that pigs do not tolerate alkaloids from *L. albus* at more than 0.12 g/kg. However, these authors reported that diets containing *L. luteus* alkaloids up to 0.45 g/kg had no negative effect on feed intake, suggesting that the type of alkaloid present may be important.

Sainfoin (*Onobrychis viciifolia*)

Currently there is interest in sainfoin for organic pig feeding. The entire plant can be used as grazed, fresh or dehydrated forage as an alternative to lucerne, and the seeds can be used as a protein feedstuff. Sainfoin is a legume that does not cause bloat in cattle, due to its tannin content. This plant is an erect, perennial herbaceous legume that can reach up to a height of 80 cm. Sainfoins are mostly subtropical plants, but their range extends from parts of Asia, the Middle East, throughout Europe and western North America.

European seed contains about 310 g/kg CP and about 400 g/kg CP (DM basis) when dehulled (Kyntäjä *et al*., 2014). According to Baldinger *et al*. (2016) sainfoin seed has a favourable AA profile and can partially replace other protein supplements in organic diets for weaned pigs when included at a level 10–16%. No reports appear to be available on the possible effects of the tannin content on protein utilization.

Tuber Roots, Their Products and By-products

Cassava

Cassava (tapioca, manioc; *Manihot esculentis crantz*) is a perennial woody shrub that is grown almost entirely in the tropics. It is one of the world's most productive crops, with possible yields of 20–30 tonnes of starchy tubers per hectare (Oke, 1990). Cassava is an approved ingredient in organic pig diets, although in many countries it will represent an imported product not produced regionally.

NUTRITIONAL FEATURES Oke (1990) reviewed the nutritional features of cassava. Fresh cassava contains about 65% moisture. The DM portion is high in starch and low in protein (20–30 g/kg, of which only about 50% is in the form of true protein). Cassava can be fed fresh, cooked, ensiled, or as dried chips or (usually) as dried meal. The meal is quite powdery and tends to produce a powdery, dusty diet when included at high levels. Cassava meal is an excellent energy source because of its highly digestible carbohydrates (700–800 g/kg), mainly in the form of starch. However its main drawback is the negligible content of protein and micronutrients.

ANTI-NUTRITIONAL FACTORS Fresh cassava contains cyanogenic glucosides (mainly linamarin), which on ingestion are hydrolysed to hydrocyanic acid and reduce pig growth. Boiling, roasting, soaking, ensiling or sun-drying can be used to reduce the levels of these compounds (Oke, 1990). Sulphur is required by the body to detoxify cyanide; therefore the diet needs to be adequate in methionine and cystine. The normal range of cyanide in fresh cassava is about 15–500 mg/kg fresh weight. It is recommended that pig diets should contain no more than 100 mg HCN equivalent/kg.

PIG DIETS Research has shown that properly processed cassava can replace maize in pig diets (Oke, 1990). Because of its powdery nature, low levels of protein and economics, the usual recommended maximum inclusion level is 400 g/kg diet. Dustiness of cassava-based diets can be reduced by adding molasses, suitable oils and by pelleting. Another possible limiting factor is the ash content. Müller *et al.* (1974) suggested that, with ash content less than 22 g/kg and CF content of 28 g/kg, the maximal inclusion of cassava can be 600 g/kg for grower diets and 750 g/kg for finisher diets. With ash and CF contents greater than 50 g/kg the corresponding maximal inclusion rates can be 200 and 400 g/kg, respectively. Limited studies suggest that cassava can be incorporated successfully in gestation and lactation diets for sows (Oke, 1990).

Potatoes (*Solanum tuberosum*)

On a worldwide basis this crop is superior to any of the major cereal crops in its yield of DM and protein per hectare. However, the potato is especially susceptible to disease and insect problems and may have received chemical treatment. Therefore any potatoes should meet organic guidelines, including being from non-GM varieties.

This tuber crop originated in the Andes but is now cultivated all over the world except in the humid tropics. It is grown in some countries as a feed crop. In others it is available for animal feeding as cull potatoes or as potatoes surplus to the human market. In addition to raw potatoes, the processing of potatoes as human food products has become increasingly common. Potatoes are also used in the industrial production of starch and alcohol. By-products of these industries are potentially useful feedstuffs. The nutritive value of these by-products depends on the industry from which they were derived. Potato protein concentrate provides a high-quality protein source, whereas potato pulp, the total residue from the starch extraction industry, or steamed peelings from the human food processing industry provide lower-quality products for swine feeding because of their higher CF and lower starch content.

NUTRITIONAL FEATURES As with most root crops, the major drawback is the relatively low DM content and consequent low nutrient density. Potatoes are variable in composition, depending on variety, soil type, growing and storage conditions and processing treatment. About 70% of the DM is starch, the CP content is similar to that of maize and the fibre and mineral contents are low (with the exception of potassium). Potatoes are very low in magnesium. Since magnesium is not usually added to pig diets, special attention should be paid to this mineral to ensure it is not deficient in pig diets containing potatoes. Of the total nitrogen in the potato tuber, 30–50% is in the form of soluble protein, 10% is insoluble protein (located mainly in the skin) and the remainder is NPN (Edwards and Livingstone, 1990). Thus potatoes are essentially a source of energy.

The DM concentration of raw potatoes varies from 180 to 250 g/kg. Consequently, when fed raw, the low DM content results in a very low concentration of nutrients per unit of weight. Expressed on a DM basis per kg, whole potatoes contain about 60–120 g CP, 2–6 g fat, 20–50 g CF and 40–70 g ash. Potato protein has a high biological value, among the highest of the plant proteins, and similar to that of soybeans. The AA profile, g/100 g CP, is typically lysine 5.3, cystine + methionine 2.7, threonine 3.2 and tryptophan 1.1. In potato protein concentrate, these values are higher (6.8, 3.6, 5.5 and 1.2 g/100 g CP, respectively) and compare very favourably with the composition of the ideal protein for pig growth (Edwards and Livingstone, 1990). The first-limiting AA in potato is generally methionine or isoleucine, and the high lysine content makes potato protein a good complement to cereal protein. Whittemore (1977) and Edwards and Livingstone (1990) published extensive reviews of the value of potatoes as a feedstuff for pigs, calves and fowl. They concluded that potatoes are potentially important as stock feed but that their use in pig feeding has given mixed results.

Raw potatoes are unpalatable to pigs (Braude and Mitchell, 1951) and are not well digested. It is now known that factors associated with the low digestibility include the structure of the starch granule, which in raw potatoes is resistant to attack by amylase in the digestive tract of the pig. Much of the starch therefore passes undigested into the caecum and large intestine where it is degraded by bacterial action (Whittemore, 1977; Livingstone, 1985), usually resulting in digestive upsets. Therefore raw potatoes should be boiled or steamed before being fed. Cooking disrupts the granular structure of the starch, allowing it to be broken down by digestive enzyme and digested. Livingstone *et al.* (1979) reported that for best results potatoes should be boiled for 30–40 min, steamed at 100°C for 20–30 min or simmered for 1 h, to ensure thorough cooking through to the centre, and then rapidly cooled. Prolonged heating, or slow cooling after heating, results in damage to the protein and a reduction in its digestibility.

A typical analysis of cooked potatoes is 222 g DM/kg, 23 g CP/kg, 7 g CF/kg, 4 g ether extract/kg and 1 g ash/kg, with a DE value of 3.83–4.02 kcal/g DM (Whittemore *et al.*, 1975; Pond and Maner, 1984). Whittemore (1977) and Edwards and Livingstone (1990) concluded that cooked potato is approximately equal to maize in DE and digestible protein contents and is palatable to pigs of all ages.

ANTI-NUTRITIONAL FACTORS The protein fraction in raw potato is poorly digested, due to the presence of a powerful protease inhibitor (Whittemore *et al.*, 1975). This inhibitor is destroyed by cooking, being absent in cooked potato (Livingstone *et al.*, 1979). The inhibitor has been shown to cause a reduction in nitrogen digestibility not only in the potato itself but also in other feedstuffs in the diet (Edwards and Livingstone, 1990). Potatoes may contain the glycoside solanin, particularly if the potatoes are green and sprouted, and may result in poisoning. Consequently, such potatoes should be avoided for feeding. The water used for cooking should he discarded and not fed to pigs because it may contain the water-soluble solanin. Ensiling was found to be ineffective in removing the factors associated with the low palatability and low digestibility in raw potatoes (Edwards and Livingstone, 1990).

PIG DIETS Growth performance has been shown to be similar when cooked potato replaced ground maize in grower-finisher diets and that problems with reduced nutrient intake were only likely to occur in young animals unable to consume the necessary daily bulk (Whittemore, 1977; Edwards and Livingstone, 1990). Growth response was also similar in young pigs given diets containing either cooked potato flakes or maize meal at 780 g/kg. In general, about 4 kg of cooked potato could replace 1 kg of barley as a source of energy and protein in the diet. Pond and Maner (1984) recommended that growing and finishing pigs could be fed up to 6 kg of cooked potatoes per day, representing about 50% of the dietary DM. They reported good results when cooked potatoes were fed to appetite along with a concentrate (1.0–1.15 kg/day) that supplied the remaining energy and nutrient needs. One benefit of potato feeding was a firm backfat. Another finding was that pellet quality of the diets was improved, the diets containing potato flakes or flour being firmer than those containing cereals. To avoid overfatness Edwards and Livingstone (1990) recommended that dry sows be restricted daily to 4–6 kg of cooked potato fed in conjunction with 1 kg of a supplementary concentrate, suggesting a similar daily amount (5–7 kg depending on live weight and litter size) in conjunction with a higher level of supplement for lactating sows.

Potato by-products

Several dehydrated processed potato products may be available for feeding to pigs. These include potato meal, potato flakes, potato slices and potato pulp. These products are very variable in their nutritive value depending on the processing method. This is particularly true of potato pulp, whose protein and fibre content depends on the proportion of potato solubles added back into the material. Therefore, it is necessary to have such materials analysed chemically before using them for feeding to pigs or to purchase them on the basis of a guaranteed analysis.

Dehydrated cooked potato flakes or flour are very palatable and can be used as a cereal replacement (Whittemore, 1977; Edwards and Livingstone, 1990). Good performance was reported when potato flakes replaced up to 50–60% of the cereals in the diets of starting, growing and finishing pigs. However, because of the high energy costs involved in their production, they are generally limited to diets for young pigs or lactating sows.

Dehydrated potato waste

This product (dehydrated potato waste meal as defined by AAFCO, 2005) consists of the dehydrated ground by-product of whole potatoes (culls), potato peelings, pulp, potato chips and off-colour French fries obtained from the manufacture of processed potato products for human consumption. It may contain calcium carbonate up to 30 g/kg added as an aid in processing. It is generally marketed with guarantees for minimum CP, minimum crude fat, maximum CF, maximum ash and maximum moisture. If heated sufficiently during processing, this product can be used successfully in pig diets.

Potato pulp

This by-product comprises the residue remaining after starch removal. The composition of the dehydrated product can be quite variable (Edwards and Livingstone, 1990) depending on the content of potato solubles. The product has characteristics similar to those of raw potato and should not be used in diets for young pigs (Edwards and Livingstone, 1990). Dietary inclusion rates of up to 15% could be used with growing-finishing pigs with little detriment to performance, provided protein supplementation was adequate, but was found to result in a reduction of killing-out percentage (Edwards and Livingstone, 1990). Higher levels were found to result in a marked deterioration in growth rate and feed conversion efficiency.

Steamed peelings

This product, sometimes called ‘liquid potato feed’, contains only partially cooked starch and has low and variable DM content (Edwards *et al.*, 1986; Nicholson *et al.*, 1988). For this reason, it is best treated in the same way as raw potato and restricted to use in diets fed to dry sows and finishing swine. Dry sows can be given 6–8 kg with 1.0–1.5 kg of a concentrate supplement daily. Steamed peelings can be included in finishing swine diets at up to 25 g/kg DM (Edwards and Livingstone, 1990), but a 5–10% reduction in performance in comparison with cereal diets should be expected. Higher inclusion levels result in decreased feed intake and poor performance. Because of the high potassium level in the product, swine should have a plentiful supply of water available. The product is best fed as soon as possible after production since it undergoes fermentation during storage with consequent loss of nutrient value. Separation of the solids, which float towards the top of the container, and moulding of the crust can also occur over time (Edwards and Livingstone, 1990). Steamed peelings which have been produced under heat and pressure contain partly denatured starch and a low concentration of protease inhibitor.

Waste potato chips

Waste or scrap potato chips, French fries or crisps, which have been cooked in oil for human consumption, are very palatable and high in energy (> 5000 kcal DE/kg) due to the fat taken up in deep frying. On a per kg basis they consist of about 500 g starch, 350 g fat, 50 g CP and 30 g minerals, mainly potassium and sodium salts. Generally they have a high salt content and a plentiful supply of fresh water should be made available if they are used in pig diets. They can be included in diets for sows and growing swine at up to 250 g/kg and in diets for younger pigs at up to 150 g/kg.

Potato protein concentrate

Potato protein concentrate is a high-quality product, widely used in the human food industry because of its high digestibility and high biological value of the protein. It is a by-product of the production of starch from potatoes and is a high-quality protein source that is suitable for use in all pig diets. However, its high cost makes it most appropriate for use in diets for young pigs. Potato protein concentrate can replace milk and fish protein in diets for young pigs at inclusion levels of up to 150 g/kg with no detrimental effects on growth or feed conversion ratio (Seve, 1977).

Sundrum *et al.* (2000) examined the effects of on-farm organic diets containing potato protein (no details on its manufacture or chemical analysis) on growth performance and carcass quality. Four dietary protein treatments were compared: a conventional diet supplemented with pure AA; faba beans supplemented with potato protein to the same AA level as the control diet; peas and lupins; or faba beans and lupins – the latter two without further supplementation, leading to a lower level of limiting AA. Supplementation of organic diets with potato protein resulted in the same performance as supplementing the conventional diet with pure AA, although CP levels differed markedly. The data from this experiment showed that the omission of AA supplementation resulted in a reduction in pig performance but in an increase in intramuscular fat content.

Swedes (*Brassica napus*)

There is current interest in root crops such as swedes for organic pig feeding, as a roughage source and as a crop to allow the animals to express natural foraging behaviour.

Livingstone *et al.* (1977) reported details of the chemical composition of swedes as a feedstuff for growing pigs and their potential as a dietary replacement for barley. Macerated swedes of the variety Balmoral were studied and were found to contain 100 g DM/kg and per kg (DM basis) 16.7 MJ DE, 128 g CP, 50 g true protein, 4 g total lysine, 26 g methionine+cystine, 408 g total sugars, 206 g ADF and 109 g ash. The composition suggested that swedes might be a replacement for barley. Pigs were grown from a live weight of 57 kg to market weight on diets containing 890 g barley plus 90 g soybean meal per kg, or on diets in which swede DM replaced 20 or 40% of barley DM. Live-weight gain per day on the three diets was 785, 735 and 732 g, respectively, and feed conversion ratios were 3.24, 3.41 and 3.45. Carcass weight gain per day was 638, 591 and 517 g, respectively, a significant reduction at each level of swede inclusion. The authors suggested that for equivalent carcass growth about 1.5 units of swede DM could replace 1 unit of barley DM, although the basis for that conclusion is not clear. This study showed that pigs given the diets containing swedes were able to consume daily amounts of DM equivalent to that of pigs receiving the control diet, but that continuous access to the feed trough was necessary. This finding indicates that sufficient feed trough space must be provided to allow all animals in the group to feed at all times when bulky feeds are used.

In subsequent work these authors tried to explain the reason for the low replacement value of swedes in relation to barley (Livingstone and Jones, 1977). Rations based on 2 kg barley plus either 0.2 or 0.4 kg soybean meal were used as controls and similar rations had swedes replacing 40% of the DM of barley. Replacement of barley with swedes reduced carcass weight gain from 620 to 510 g/day and increasing the content of soybean meal increased it from 540 to 590 g/day. The authors concluded that the low replacement value of swedes was not due to its protein component but to other factors.

Sows appear to like swedes and when they have access to this crop spend less time rooting in paddocks (Edge *et al.*, 2005). This study suggested that the daily concentrate ration could be reduced by 0.5 kg in sows provided with access to swedes.

Forages and Roughages

Cabbage (*Brassica oleracea*, Capitata group)

Cabbages have a high yield of nutrients per hectare and are of potential interest for organic feeding as a source of roughage. However, little research appears to have been conducted on this crop as a feed ingredient for pigs. Livingstone *et al.* (1980) used comminuted cabbage (variety Drumhead) in diets for growing-finishing pigs as a partial replacement for barley and soybean meal. The cabbage contained 100 g DM/kg and contained per kg (DM basis) 18 MJ GE, 230 g CP, 79 g true protein, 7.6 g total lysine, 4.7 g methionine + cystine, 142 g ADF and 132 g ash. Replacing a mixture of 805 g barley and 180 g soybean meal (DM basis) with 150 or 300 g cabbage (DM basis) reduced the rate of carcass weight gain by 12.2 and 18.5%, respectively.

Grass meal

NUTRITIONAL FEATURES There is a lack of recent documented information on the nutritive value of grass meal for pigs. However, this product is an established feed ingredient in Europe, based on research carried out over 50 years ago. For instance, Karunskii (1988) described a traditional Moldavian diet for growing pigs as containing maize meal, pea meal, barley meal, meat-and-bone meal, grass meal, wheat bran, protein and vitamin–mineral supplement. Artificially dried young grass at levels up to 200 g/kg has been used with growing-finishing pigs, in diets containing grains and other feeds of equivalent energy value, plus 2 litres of skimmed milk per head per day (Frens, 1943). Woodman and Evans (1948) recommended that grass meal should form not more than 33% of the diet up to 150 lb (68 kg) live weight and that above 150 lb live weight it was advantageous to reduce it to 25%.

Grass meal does not appear to be utilized by growing pigs as well as lucerne meal. Meal prepared from lucerne cut at the budding stage and awn-less bromegrass cut at ear formation were compared by Popelov (1981). The lucerne meal contained 148 g digestible protein/kg and the grass meal 80 g/kg. Large White pigs were fed from a body weight of 31 kg for 120 days on a control diet of 950 g mixed feed/kg and 50 g lucerne meal/kg, on 850 g mixed feed/kg and 150 g lucerne meal/kg, or on 850 g mixed feed/kg and 150 g bromegrass meal/kg. Average daily gain was 575, 548 and 489 g, respectively, and the pigs required 4.57, 4.82 and 5.40 feed units/kg gain. A study by Andersson and Lindberg (1997a,b) found that the grass meal was not as well digested as lucerne (Table 4.3), although containing less CF and more sugars than lucerne. Their results indicated that much of the breakdown in the gut was in the form of fermentation in the large intestine, and suggested that grass meal would be more suitable for sows than growing-finishing pigs.

Another factor influencing the utilization of grass meal is the stage of maturity at harvesting. Vestergaard *et al.* (1995) reported the composition of dried grass meal from different seasonal cuts of a ryegrass (*Lolium* spp.)/red clover (*Trifolium pratense*) pasture and its apparent digestibility in growing pigs and sows (Table 4.4). Dried grass meal derived from the first, second and third cut of a ryegrass/red clover pasture showed reduced sugar content, increased content of dietary fibre and decreased apparent digestibility. Digestibility measurements were investigated separately for growing pigs (40–60 kg live weight) and adult sows (approximately 200 kg live weight). Both groups showed a similar decline in digestibility across samples,

Table 4.3. Digestibility of lucerne and grass meals in growing pigs (from Andersson and Lindberg, 1997a,b).

	Lucerne (*Medicago sativa*)	Ryegrass (*Lolium* spp.)
Composition (g/kg dry matter)		
Crude fibre	341	236
Sugars	6	29
Crude protein	174	152
Ileal digestibility		
Organic matter	0.12	−0.02
Crude protein	0.52	0.09
Energy	0.10	−0.20
Total tract digestibility	0.40	
Organic matter	0.49	0.22
Crude protein	0.35	0.08
Energy	0.35	0.04

Table 4.4. Digestibility of grass cut at various stages of maturity in growing pigs and sows (from Vestergaard *et al*., 1995).

	Cut 1	Cut 2	Cut 3
Analysis (g/kg dry matter)			
Crude fibre	231	275	286
Cellulose	165	208	212
Sugars	141	99	57
Dry matter digestibility (%)			
Growing pigs	58	45	40
Sows	62	53	50
Crude protein digestibility (%)			
Growing pigs	13	17	11
Sows	39	39	36
Metabolizable energy (MJ/kg dry matter)			
Growing pigs	9.6	7.4	6.3
Sows	10.1	8.8	8.3

but sows showed a consistently higher digestibility of herbage than growing pigs, which was attributable to higher digestibility of the fibre fraction. The higher CP digestibility value recorded in this study may be attributed to the presence of clover in the grass mixture. The greater gut capacity and slower rate of passage in adult sows increase their ability to obtain nutrients from fibrous feeds as a result of hindgut fermentation, and hence makes them better equipped to utilize herbages. Other factors that need to be considered are the question of bulk and adaptation to grass meal in the diet.

PIG DIETS Some organic producers wish to include grass meal in diets for growing-finishing pigs and for sows, as a source of roughage and as a natural source of nutrients. European findings suggest that good-quality grass meal can be included successfully at low levels in diets for young pigs (Gamko, 1983). Similar findings have been obtained with growing pigs of 30–60 kg live weight (Skomial, 1988). Grass meal included at 140 g/kg to replace barley in the feed mix had no adverse effect on daily gain and efficiency of feed utilization, although digestibility of organic matter, CP and NFE decreased with increasing proportion of grass meal in the diet. Barley was ground to particle size of 3 and 5 mm and grass meal to 3 and 6 mm. Grinding barley, but not the grass meal, to a lower particle size improved digestibility.

Data on the effects of grass meal in sow diets are lacking. However, an average daily intake of 7.5 kg fresh herbage was recorded in dry sows by Edwards (2003). That corresponds to an intake of about 1.2 kg DM/day, suggesting that a level of up to 500 g grass meal/kg could be included in the diet of gestating sows as a way of providing bulk and attaining gut-fill.

Lucerne (*Medicago sativa* L., *Medicago* spp.)

Lucerne (alfalfa) is one of the most widely grown forage crops on a global basis and is the most widely used legume forage meal in pig diets (Chiba, 2001). It is a good source of many nutrients and in the past the inclusion of lucerne meal was considered to be essential in diets for breeding pigs. Unfortunately, lucerne is relatively unpalatable, the protein is poorly digested, and it has a low DE value owing to its high fibre content. Despite its shortcomings, there is still considerable interest in using lucerne in organic pig diets as a roughage source. Maturity of the plant at the time of harvest greatly influences nutritional quality, with the quality being highest in cuts taken at the pre-bloom or early bud stage. Nutrient losses can occur through field damage by sunlight and rain; therefore much of the lucerne for animal feeding is dehydrated after harvesting. A moisture content of 90 g/kg maximum has been suggested for storage of sun-cured (air-dried) lucerne.

NUTRITIONAL FEATURES Sun-cured lucerne is the aerial portion of the lucerne plant. According to the North American feed regulations, the traded product which has been sun-cured and finely ground has to be reasonably free of other crop plants, weeds and mould.

A summary of the nutrient content of lucerne has been presented by Chiba (2001). Most of the data refer to the dehydrated product, which is generally of higher quality than the sun-cured product. The CP content of lucerne ranges from 120 to 220 g/kg and the CF content from 250 to 300 g/kg. The accessibility of digestive enzymes to the soluble cellular proteins is reduced by the high fibre content. As a result the protein in lucerne has a digestibility of approximately 0.6. Lucerne contains a relatively high content of lysine, and has a good AA balance. Sun-cured lucerne is high in calcium and its bioavailability can be similar to calcium carbonate when fed to gestating sows (Walker *et al.*, 1993). Lucerne is low in phosphorus, but it is a good source of other minerals and of most vitamins. The fibre component of lucerne meal (and other sources of fibre) is fermented in the hindgut, producing volatile fatty acids which can provide up to 30% of the maintenance energy requirement, thus possibly partitioning other nutrients for tissue growth (Stahly and Cromwell, 1986).

ANTI-NUTRITIONAL FACTORS Lucerne contains saponins and tannins. The saponins are bitter compounds, unpalatable to the pig. As a result the palatability of diets containing lucerne is reduced and pigs do not consume sufficient feed to compensate for the energy dilution caused by the fibre. The discovery of Turkish strains that are essentially devoid of haemolytic saponins may lead to a greater usage of lucerne in pig diets. Lucerne also contains about 32.5 g tannins/kg (Thacker, 1990d). These are water-soluble polymeric phenolic compounds that can depress protein digestibility by binding dietary protein and inhibiting digestive enzymes. Tannins may also reduce feed intake. In addition, lucerne may contain a trypsin inhibitor and a photosensitizing agent.

PIG DIETS Because of its high fibre content and possible palatability problems, lucerne meal should not be used in the diet for weanling pigs (Chiba, 2001). Seerley (1991) suggested that grower-finisher pigs can be fed dietary levels of 25–100 g lucerne meal/kg. Rate and efficiency of weight gain were, however, found to decrease progressively as the content of lucerne meal increased from 0 to 600 g/kg (Kass *et al.*, 1980; Powley *et al.*, 1981).

The use of lucerne in gestation diets has a long history, and most research has indicated little or no detrimental effects of lucerne on reproductive performance of sows (Chiba, 2001). In addition, inclusion of lucerne in sow diets has been shown to increase ovulation rate, litter size at birth, pig survival rate, farrowing percentage and longevity. The beneficial effects of lucerne in improving litter size at birth and survival rate may be related to increased ketogenic substrates in sows fed high-fibre diets. A review by Thacker (1990d) suggested that levels as high as 600 g/kg diet can be used. However there was some evidence that high levels of dietary lucerne might reduce birth weight of the piglets. Lucerne meal was not recommended for inclusion in lactation diets but could be used before farrowing and during early lactation to prevent or alleviate constipation.

Silage

Lucerne silage can be used in pig diets, provided its limitations (bulk, high-moisture content and relatively low content of energy and nutrients) are taken into account. Clements *et al.* (2015) fed Gloucester Old Spot weaner gilts and entire boars *ad libitum* on diets based on 55% lucerne silage, 30% rolled barley and 1% mineral mix, and a supplement of 14% soybean meal, faba beans or field peas. No significant difference in daily live weight gain was observed during the grower phase (11–14 weeks) between the diet groups, but during the finisher phase (15–22 weeks), the pigs fed the soy and pea diets had significantly faster growth rates than pigs fed the faba bean diet.

Vetch (*Vicia sativa*)

Common vetch has been studied as an alternative protein source for pigs in southern Australia (Collins *et al.*, 2002). It is considered to have potential as a valuable protein source in pig diets since it has been reported to contain 284 g CP, 17.7 g lysine and 14.3 MJ DE per kg. However, the use of vetch grain in pig diets has not been recommended in Australia due to the anti-nutritional properties of traditional vetch varieties, which can have adverse effects on feed intake and growth performance. The mature seed contains a neurotoxin, which affects the conversion of methionine to cysteine and has indirect effects on glutathione metabolism. However, newer cultivars of vetch, e.g. Morava, have low levels of this toxin.

A study by Collins *et al.* (2002) was designed to determine the maximum inclusion level of common vetch (*Vicia sativa* cv. Morava) in the diet of growing pigs. The experiment involved 312 pigs that were selected at 91 days of age and 38 kg at the start and housed commercially. Four diets were tested, each formulated to contain 11.6 g lysine/kg and 14 MJ DE/kg, with vetch replacing peas at levels of 0, 75, 150 and 225 g/kg. Pigs were fed the diets *ad libitum* between 91 and 119 days of age. The overall growth performance was found to be satisfactory on all diets, with no significant effects of dietary vetch on growth rate, feed intake or feed conversion ratio. The researchers concluded that growing pigs can be fed common vetch (*V. sativa* cv. Morava) up to 225 g/kg between 91 and 119 days of age without affecting overall growth performance.

Other Plants and Plant By-products

Molasses

Molasses is used in organic diets as a pellet binder. This product is a by-product of sugar production, and is produced mainly from sugarcane (*Saccharum officinarum*) and sugarbeet. Some tropical countries that grow sugarcane and have surplus molasses, such as Cuba, have developed pig production systems based on liquid feeding of sugarcane as a replacement for maize.

NUTRITIONAL FEATURES Molasses generally contains 670–780 g DM/kg and can vary widely in composition due to soil and growing and processing conditions. The carbohydrate content is high, being composed mainly of highly digestible sugars (primarily sucrose, fructose and glucose). The CP content is low (range 30–60 g/kg). Molasses should therefore be regarded as a low-energy product. It is usually a rich source of minerals; the calcium content of cane molasses being high (up to 10 g/kg) due to the addition of calcium hydroxide during processing but the phosphorus content is low. Cane molasses is also high in sodium, potassium and magnesium. Beet molasses tends to be higher in both potassium and sodium but lower in calcium content. Molasses also contains significant quantities of copper, zinc, iron and manganese and can be a good source of some B vitamins such as pantothenic acid, choline and niacin.

PIG DIETS Molasses is used in organic pig diets at levels around 25–50 g/kg as a pellet-binding agent. This is attributed to its capacity to allow the feed granules to stick together during the pelleting process and produce pellets that are less likely to break down during transportation and passage through feeding equipment. Additional benefits of molasses addition are a possible increase in palatability of the diet and a reduction in dustiness of the dietary mixture. Higher dietary levels are known to have a laxative effect on pigs, allowing molasses to be used at dietary levels of 100–200 g/kg to correct problems of constipation in sows at farrowing time.

Molasses levels above 700 g/kg have been used successfully in pig production systems in Cuba (studies conducted by Preston and co-workers; cited in Pond and Maner, 1984) and its use extended to other tropical regions and also to systems based on the feeding of sugarcane juice.

Seaweeds

Seaweeds (kelp) contain significant quantities of minerals but tend to be low in other nutrients. In some regions they are harvested as dried fodder for farm livestock in coastal areas. China is a major seaweed producer, growing over 2.5 million tonnes of the brown alga *Laminaria japonica*. There is considerable potential for increasing kelp production, particularly in regions such as the Pacific coast of North America. Canada has the longest coastline of any nation, suggesting that greater use should be made of this plant resource. In addition, Canada's marine environment is probably less polluted than elsewhere. A recent development in North America is the use of seaweed as a substrate for biogas (methane) production.

The composition of seaweed differs according to species and naturally occurring changes in the plant.

Feeding studies with pigs show that it is not a good source of energy or protein and is not well digested (Beames, 1990). Furthermore adding kelp to the diet reduces the digestibility of the major feed components in the other ingredients. The conclusion of most studies is, therefore, that kelp should be regarded as a trace mineral source, for use at low levels in the diet after washing, drying and grinding.

Seaweed has been shown to be of value in the control of parasites. Jensen (1972) reported that inclusion of seaweed in the diet markedly reduced the incidence of liver condemnations from ascarid damage in pigs at slaughter. This aspect of seaweed inclusion is of interest to organic farmers but does not appear to have been investigated further.

Milk and Milk Products

Cow's milk is an excellent source of nutrients and, when surplus to requirements for the human market, can be used with all classes of pig. Generally it is milk by-products that are used in pig feeding, in either liquid or dried (dehydrated) form, and mainly in diets for young pigs because of cost and availability. Adequate heat treatment (pasteurization) should have been applied to all milk products to ensure that any pathogenic organisms have been destroyed. Generally, the AA availability of milk products is considered high, but their quality can be impaired by overheating.

By-products in liquid form

Skimmed (separated) milk

This product consists of milk from which most of the fat has been removed but which contains all of the protein. The protein has a high biological value and is very digestible. Skimmed milk is a good source of B vitamins, but the fat-soluble vitamins (A and D) have been removed with the fat. Growth rates in growing pigs were increased when skimmed milk was included in the diet (Dunshea *et al.*, 1999). Scouring can be a problem with skimmed milk feeding if precautions are not taken to feed at regular intervals. Skimmed milk should either be fresh or always at the same degree of sourness. Attention should be paid to the cleanliness of the equipment used for feeding. Normal bacterial acidification can be used as an effective and convenient method of stabilization.

Recommendations for the feeding of liquid skimmed milk to growing-finishing pigs are given in Table 4.5. The feed composition for this particular use can contain 50 g premix/kg. The premix should contain calcium, phosphorus, iron, zinc, iodine, selenium, sodium chloride (salt) and vitamins A, D and E.

Dunshea *et al.* (1999) reported that the feeding of skimmed milk to early-weaned pigs before and after weaning improved their growth performance. In this study, litters suckled the sow only or received supplemental liquid skimmed milk (200 g/l) *ad libitum* from day 10 until day 20. On day 20 the four heaviest pigs of each sex were allocated to two pairs and were weaned. Each pair was offered either pelleted feed or pelleted plus liquid feed. For the first two

Table 4.5. Feeding recommendations for the feeding of liquid skimmed milk to growing-finishing pigs.

Weight of pig (kg)	Ratio feed: skimmed milk	Feed per pig per day (kg)	Skimmed milk (l or kg)
20–40	1:4	0.6–1.1	2.3–2.7
40–60	1:3	1.2–1.6	3.2–3.6
60–100	1:2	2.3–2.5	3.6–4.1

days post-weaning, each pair of liquid-supplemented pigs received liquid skimmed milk (250 g/l). On day 23, pelleted feed was added to the milk. The ratio of liquid to pelleted feed was adjusted daily so that on day 28 pigs were provided with pelleted feed only until 41 days of age. Supplemental skimmed milk increased growth (223 versus 291 g/day) between 10 and 20 days of age, so that by weaning the pigs fed the supplemented diets were 10% heavier (6.13 versus 6.74 kg). The growth lag usually experienced after weaning was reduced in this study, pigs weaned onto skimmed milk and pellets eating more (257 versus 30 g DM/day) and growing faster (+213 versus −151 g/day) over the first two days post-weaning than pigs weaned onto pellets only. Piglets provided with skimmed milk after weaning continued to grow faster to at least 41 days of age (14.1 versus 12.8 kg).

Buttermilk

This is the liquid product remaining after whole milk is churned and the butter removed. It usually contains more fat than skimmed milk. Buttermilk is more acidic than skimmed milk and can have more of a laxative action in pigs. It is an excellent source of supplemental protein for young pigs, daily gain being improved when buttermilk replaced soybean meal (Christison and de Solano, 1982).

Whey

Whey is the liquid by-product remaining after cheese production. Whey contains about 90% of the lactose, 20% of the protein, 40% of the calcium and 43% of the phosphorus originally present in milk. However, its DM content is low, around 70 g/kg. Most of the fat and protein are removed during processing, leaving the whey high in lactose and minerals. The high lactose content does not normally cause problems in young pigs which have been adapted to a milk-based diet, but may cause problems in older pigs and sows due to an inadequate production of intestinal lactase. As a result, whey should be fed in restricted quantities to finishing pigs and sows.

In addition to providing nutrients, whey can also be used as a source of water. Whey should be warmed or allowed to reach room temperature before being offered to pigs. Cold whey may reduce intake. Also, pigs should be introduced gradually to the product, to prevent digestive disturbances and diarrhoea. Usually two types of whey are available commercially, fresh and acidified. Fresh (sweet) whey is used in pig diets in the fresh state, without storage during which it is allowed to ferment and become acidic. However, fresh whey deteriorates rapidly and needs to be used within a short time of production. Acid whey is allowed to ferment and become acidic naturally. It is more stable than fresh whey as a result of the acidity. However, acid whey is less palatable than fresh whey. Sometimes acids, such as formic acid and hydrochloric acid, are used to stabilize whey. If used, they should be acceptable for organic pig production.

Whey is a very dilute feed, consisting of 930 g water and 70 g DM per kg, and contains less than 10 g CP/kg on a wet basis (130 g CP/kg on a DM basis). The protein is of excellent quality because of the AA balance. It should be introduced into the diet gradually. The *ad libitum* feeding of liquid whey to young pigs has been shown not to cause any problems (Brocksopp, 1979). A common feeding system used on conventional farms is to utilize grain such as barley supplemented with minerals and vitamins and whey *ad libitum* as the complete diet. The DM in liquid whey can be used to supply up to 30% of the total diet, about 7–14 l per pig daily depending on body weight. A feeding system that gave satisfactory results with growing-finishing pigs was described by Cortez *et al.* (cited in Pond and Maner, 1984). During the growing phase (to 50 kg) the pigs consumed on a daily basis an average of 11 l of liquid whey on *ad libitum* feeding plus an average of 1.25 kg of a dietary mixture containing 160 g CP/kg. During the finishing phase (to 95 kg) the intakes were, respectively, 16 l and 2.25 kg of a dietary mixture with 130 g CP/kg.

An interesting finding was that whey feeding was found to reduce ascarid egg count in the faeces of pigs (Alfredsen, 1980), suggesting that this product could be used as a natural de-wormer.

Lactase appears to be produced in the gut in sufficient quantity in older pigs fed whole milk or skimmed milk, but the higher concentration of lactose in liquid whey may cause problems in older pigs such as sows (Pond and Maner, 1984), resulting in digestive problems due to excessive fermentation of undigested lactose in the large intestine. Should this occur the amount fed should be restricted.

Dried milk products

Dried milk products include dried whole milk, dried skimmed milk and dried whey. The products derived from whole milk and skimmed milk are very palatable and highly digestible protein supplements with an excellent balance of AA. They are good sources of vitamins and minerals (Seerley, 1991), except fat-soluble vitamins, iron and copper. Although generally too expensive for use as a feed ingredient, some dried skimmed milk has been used in pig starter diets when available economically. Research emphasis in this area has been to replace dried skimmed milk with alternative protein supplements in weanling pig diets rather than evaluating the value of the dried milk per se. Dried whole milk and skimmed milk can be fed successfully to all classes of pig; thus, the use of these products in pig diets should be determined mostly on economics (Seerley, 1991).

Whey, dried

Dried whey contains about 650 g of lactose per kg, which has been shown to be the best sugar for baby pigs (Cunha, 1977). It contains about 130–170 g of high-quality protein per kg (Seerley, 1991). Dried whey is an excellent source of B vitamins, most of which remain in the whey during cheese production, but it may be low in vitamins A and D, which are retained in the cheese (Seerley, 1991). Season, type of cheese produced and geographic location can have an effect on the mineral content (Leibbrandt and Benevenga, 1991). The efficacy of high-quality dried whey in enhancing growth performance of weanling pigs has been well established over the years (Graham *et al*., 1981; Cera *et al*., 1988). The composition and quality of dried whey is, however, more variable than that of other milk products (Tomkins, 1989); therefore it is important to use a high-quality product. Mahan (1984) found that low-quality dried whey added to a maize/soybean meal diet did not result in improved growth rate, whereas dried whey of high quality improved growth rate by approximately 15%.

Studies have been carried out to determine whether factors other than lactose content and high nutrient digestibility might be responsible for the beneficial effects of dried whey on weanling pig performance. By including either lactalbumin or lactose in the diet, Tokach *et al*. (1989) concluded that both the protein and carbohydrate fractions of dried whey are important. Lepine *et al*. (1991) and Mahan *et al*. (1993), however, reported that the protein fraction was not a limiting factor in weanling pig diets. After evaluating the efficacy of lactalbumin and lactose components of dried whey, Mahan (1992) concluded that the lactose component of dried whey was primarily responsible for the beneficial effects of dried whey. It has been shown that edible-grade de-proteinized whey and crystalline lactose can replace the lactose provided by high-quality dried whey without affecting pig performance (Nessmith *et al*., 1997). In other research Mavromichalis *et al*. (2001) reported that replacing lactose with sucrose or molasses did not affect weight gain, feed intake, or efficiency of feed utilization or nutrient digestibility. Apparent digestibilities of DM and nitrogen were greater in pigs fed complex diets versus simple diets, but they were not affected by sugar additions. The distinction between simple and complex diets was based on the type of ingredients used. The complex diets were supplemented with whey protein concentrate, animal plasma protein and wheat gluten, whereas simple diets were supplemented with fishmeal only.

Dried whey can be fed to all classes of pig, but it is primarily used for weanling pigs. As reviewed by Pond and Maner (1984) and Seerley (1991), an inclusion rate of 100–300 g/kg is commonly used, although 300–450 g/kg can be included without any adverse effects. The optimum inclusion rate of dried whey in pig diets should be determined mainly by cost. Pond and Maner (1984) suggested a gradual reduction in the level of dried whey in the diet as pigs reach market weight.

Fish, Other Marine Animals, Their Products and By-products

Fishmeals

Although not an organic product in the strict sense, fishmeal is approved for use in organic pig diets provided it is from a sustainable source and any antioxidant added to prevent spoilage is from the permitted list. Oil-extracted fishmeal should have been processed by a mechanical method. Fishmeal is defined as the clean, dried and ground tissues of non-decomposed whole fish or fish cuttings, with or without extraction of the oil. Some is made from fish waste of fish processed for the human food market, the rest from whole fish caught specifically to be made into fishmeal. The type of fish used has a major influence on the composition of the meal. White fish have low oil content, while members of the herring family (e.g. menhaden, anchouetta and pilchard) contain high amounts of oil. Major producers of fishmeal are Peru and Chile. Fishmeal used for feed in North America must not contain more than 100 g moisture/kg or 70 g salt/kg, and the amount of salt must be specified if it is greater than 30 g/kg. Antioxidants are commonly added to the meal to prevent oxidation and spoilage; therefore this aspect should be checked for acceptability in organic diets.

NUTRITIONAL FEATURES Fishmeal is well established internationally as an excellent feedstuff for pigs (Bellis, 1974), although its current availability and cost (because of competing demands from aquaculture and the pet-food industry) tend to limit it to diets for young pigs and lactating sows. The quality of fishmeal can vary greatly depending on the quality of fish materials used, processing factors such as overheating and oxidation of the meal (Seerley, 1991; Wiseman *et al.*, 1991). Fishmeals are generally high in protein (50–75%) and EAA, particularly lysine, that are deficient in many cereal grains and other feedstuffs. Most mineral elements, especially calcium and phosphorus, and B vitamins are relatively high compared with other protein sources and the phosphorus is of high availability.

Fishmeal is an important and sometimes the only source of animal protein in most Asian countries (Ravindran and Blair, 1993). It is either imported or is produced locally. The local fishmeals contain between 400 and 500 g CP/kg, but are generally of low quality due to lack of control over raw fish quality, processing and storage conditions. Also, they are often adulterated with cheap diluents such as sand. Samples containing as much as 150 g salt/kg are not uncommon. This situation underlines the need for strict enforcement of quality control measures in several Asian countries.

PIG DIETS Fishmeal is regarded as one of the best sources of protein in diets for young pigs and lactating sows. Weanling pigs fed diets containing fishmeal in combination with milk products or soybean meal had better growth performance than those fed diets with processed soybeans with added lysine or soybean meal (de Moura and Fowler, 1985; Newport and Keal, 1983). However these protein sources generally had no effect on apparent digestibility of nitrogen and AA, or on nitrogen retention. The effect of dietary inclusion of fishmeal at 50 g/kg on the performance of pigs from 3 or 5 weeks of age until slaughter at 90 kg was evaluated by Pike (1984). Growth rate and feed efficiency were reduced in pigs fed the diet without fishmeal. A great deal of research has been conducted recently to find cheaper and more available alternative protein sources for weanling pig diets, such as potato protein and spray-dried plasma (Kerr *et al.*, 1998).

Laksesvela (1961) reported that weight gain and feed efficiency in grower-finisher pigs were increased as dietary fishmeal increased from 0 to 120 g/kg, but most of the response was obtained with the initial levels of 60–80 g/kg. Carcass quality was not affected with fishmeal levels of 60–80 g/kg. However, it is recommended that the amount of fishmeal in pig diets should not exceed 60–70 g/kg because of its potential to cause a fishy flavour in pork, and also that its use should be avoided in the diets of pigs approaching slaughter weight. The use of fishmeal in diets for growing-finishing pigs has declined in recent years because of cost and supply problems and the availability of cheaper alternatives such as soybean and canola meals.

Fishmeal prepared from locally caught fish is important in developing regions in providing protein to balance pig diets (Kumar *et al.*, 2000; Nguyen *et al.*, 2005). One interesting aspect of the work described in India by Kumar *et al.* (2000) is that it involved Tamworths. There are few published scientific reports of nutritional investigations involving this breed.

Mineral Sources

Approved ingredients are outlined in detail in Tables 4.6 and 4.7. However, it is necessary to clarify use of the term 'organic' that can be found in relation to certain classes of ingredients such as mineral sources. Organic minerals are minerals containing carbon, following standard chemical nomenclature. In this context

Table 4.6. Concentrations of mineral elements in common dietary mineral sources.

Source	IFN	Formula	Mineral	Concentration (%)
Limestone, ground	6-02-632	$CaCO_3$ (mainly)	Calcium	38
Calcium carbonate	6-01-069	$CaCO_3$	Calcium	40
Oyster shell, ground	6-03-481	$CaCO_3$	Calcium	38
Dicalcium phosphate	6-01-080	$CaHPO_4{\cdot}2H_2O$	Calcium	23
			Phosphorus	18
Defluorinated phosphate	6-01-780		Calcium	32
			Phosphorus	18
Phosphate, Curaçao	6-05-586		Calcium	36
			Phosphorus	14
Salt, common	6-14-013	NaCl	Sodium	39.3
			Chloride	60.7
Copper sulphate		$CuSO_4{\cdot}5H_2O$	Copper	25.4
Copper carbonate		$CuCO_3{\cdot}Cu(OH)_2$	Copper	55
Copper oxide		CuO	Copper	76
Calcium iodate		$Ca(IO_3)_2$	Iodine	62
Potassium iodide		KI	Iodine	70
Ferrous sulphate		$FeSO_4{\cdot}H_2O$	Iron	31
Ferrous sulphate		$FeSO_4{\cdot}7H_2O$	Iron	21
Ferrous carbonate		$FeCO_3$	Iron	45
Manganous oxide		MnO	Manganese	77
Manganous sulphate		$MnSO_4{\cdot}H_2O$	Manganese	32
Sodium selenite		$NaSeO_3$	Selenium	45
Sodium selenate		$NaSeO_4$	Selenium	41.8
Zinc oxide		ZnO	Zinc	80
Zinc sulphate		$ZnSO_4{\cdot}H_2O$	Zinc	36
Zinc carbonate		$ZnCO_3$	Zinc	52

IFN, International Feed Number.
The bioavailability of the named minerals in the above forms is high or very high. The exact concentration of minerals will vary, depending on the purity of the source.
The above sources may also provide trace amounts of minerals other than those listed, such as sodium, fluoride and selenium.
Cobalt-iodized salt is often used as a source of sodium, chloride, iodine and cobalt.
Other sources may be permitted in organic diets and producers should check with the local certifying agency for details. For instance, in the US regulations (FDA, 2001) the approved list of trace minerals with GRAS (Generally Recognized As Safe) status when added at levels consistent with good feeding practice includes those listed in Table 4.7.

Table 4.7. Trace minerals for use in animal feed approved by the US Food and Drug Administration.

Trace mineral	Approved forms
Cobalt	Cobalt acetate, carbonate, chloride, oxide, sulphate
Copper	Copper carbonate, chloride, gluconate, hydroxide, orthophosphate, prophosphate, sulphate
Iodine	Calcium iodate, iodobehenate; cuprous iodide; 3,5-diiodosalicylic acid; ethylenediamine dihydriodide; potassium iodate; potassium iodide; sodium iodate; sodium iodide
Iron	Iron ammonium citrate; iron carbonate, chloride, gluconate, lactate, oxide, phosphate, pyrophosphate, sulphate; reduced iron
Manganese	Manganese acetate, carbonate, citrate (soluble), chloride, gluconate, orthophosphate, phosphate (dibasic), sulphate; manganous oxide
Zinc	Zinc acetate, carbonate, chloride, oxide, sulphate

the term 'organic' does not mean derived from an organic source. Minerals not containing carbon are termed inorganic, following standard chemical nomenclature. Organic minerals such as selenomethionine are used in conventional feed manufacture, but very few appear to be approved for use in organic pig diets. Some are approved under the US regulations. These organic sources may provide minerals in a more bioavailable form than inorganic sources. Producers wishing to use them should check their acceptability with the local certifying agency.

Vitamin Sources

Vitamins from synthetic sources are permitted in organic diets for pigs.

A main concern for the nutritionist and feed manufacturer in selecting vitamins for inclusion in diets is their stability. In general, the fat-soluble vitamins are unstable (Combs, 1992) and they must be protected from heat, oxygen, metal ions and ultraviolet light. Antioxidants are frequently used in conventional feeds, to protect these vitamins from breakdown. All of the naturally occurring forms of vitamin A (retinol, retinal and β-carotene) with the exception of retinoic acid are particularly unstable and sensitive to ultraviolet light, heat, oxygen, acids and metal ions. The naturally occurring forms of vitamin E (mainly tocopherols) are readily oxidized and destroyed by peroxides and oxygen in a process accelerated by PUFA and metal ions. Because of the instabilities of their naturally occurring vitamers (forms of the vitamin), the concentrations of fat-soluble vitamins in natural foods and feedstuffs are highly variable, being greatly affected by the conditions of production, processing and storage. Consequently the synthetic esterified forms (acetate and palmitate), which are much more stable, are preferred for diet formulation.

Vitamin D is available as D_2 (ergocalciferol) and D_3 (cholecalciferol). Pigs can utilize either source but since poultry can utilize only the D_3 form it is usual to supplement all feeds (where necessary) with the D_3 form. Fish oil is allowed under the Canadian Feeds Regulations as a source of vitamins A and D.

The commonly available source of stable vitamin E used in animal feed is synthetic DL-α-tocopheryl acetate. An alternative form of stable vitamin E is D-α-tocopheryl acetate, which is derived from plant oils (such as soybean, sunflower and maize). This form has a relative biopotency of more than 136% in comparison with DL-α-tocopheryl acetate.

The potency of the fat-soluble vitamins is expressed in terms of international units (IU).

The water-soluble vitamins tend to be more stable under most practical conditions, exceptions being riboflavin (which is sensitive to light, heat and metal ions), pyridoxine (pyridoxal, which is sensitive to light and heat), biotin (which is sensitive to oxygen and alkaline conditions), pantothenic acid (which is sensitive to light, oxygen and alkaline conditions) and thiamin (which is sensitive to heat, oxygen, acidic and alkaline conditions, and metal ions) (Combs, 1992). Again, the more stable synthetic forms of these vitamins are used in conventional feed formulation. Choline chloride is very hygroscopic (absorbs water when exposed to air) and the non-hygroscopic choline bitartrate is a preferred source of this vitamin.

Vitamins allowed for addition to animal feeds under the Canadian Feeds Regulations (Class 7. Vitamin products) are listed below. All have to be labelled with a guarantee of declared potency.

Class 7. Vitamin products and yeast products

7.1 [Repealed, SOR/97-151, s. 16]
7.2 Beta-carotene (IFN 7-01-134) is beta-carotene formulated in an organic matrix. It is a vitamin A precursor for all species except mink. It shall be labelled with a guarantee for minimum milligrams of beta-carotene per kilogram.
7.3 Vitamin A (IFN 7-05-142) is an acetate ester, a palmitate ester, a propionate ester or a mixture of these esters of retinol formulated in an organic matrix. It shall be labelled with a guarantee for minimum international units of vitamin A per kilogram.
7.4 Vitamin D3 (IFN 7-05-699) is cholecalciferol formulated in an organic matrix. It shall be labelled with a guarantee for minimum international units of vitamin D3 per kilogram.
7.5 Vitamin E (IFN 7-05-150) is an acetate ester, a succinate ester or a mixture of these esters of dl-alpha tocopherol adsorbed on a carrier or formulated in an organic matrix. It shall be labelled with a guarantee for minimum international units of vitamin E per kilogram.
7.1.1 *p*-Aminobenzoic acid (IFN 7-03-513) is para-aminobenzoic acid. It shall be labelled with a guarantee for minimum milligrams of para-aminobenzoic acid per kilogram.
7.1.2 Ascorbic acid (IFN 7-00-433) is vitamin C. It shall be labelled with a guarantee for minimum milligrams of ascorbic acid per kilogram.
7.1.3 Betaine hydrochloride (IFN 7-00-722) is the hydrochloride of betaine. It shall be labelled with a guarantee for minimum milligrams of betaine hydrochloride per kilogram.
7.1.4 d-Biotin (IFN 7-00-723) is hexahydro-2-oxo- 1H-thieno 3,4-d imidazole-4-pentanoic acid. It shall be labelled with a guarantee for minimum milligrams of d-biotin per kilogram.
7.1.5 Calcium d-pantothenate (IFN 7-01-079) is the calcium salt of d-pantothenic acid. It shall be labelled with a guarantee for minimum milligrams of calcium d-pantothenate per kilogram. It shall also be labelled with a statement indicating the equivalent minimum milligrams of d-pantothenic acid per kilogram.
7.1.6 Calcium d1-pantothenate (IFN 7-17-904) is the calcium salt of racemic d1-pantothenic acid. It shall be labelled with a guarantee for minimum milligrams of calcium d1-pantothenate per kilogram. It shall also be labelled with a statement indicating the equivalent minimum milligrams of d-pantothenic acid per kilogram.
7.1.7 Choline chloride solution (IFN 7-17-881) is an aqueous solution of choline chloride. It shall be labelled with a guarantee for minimum milligrams of choline chloride per kilogram.
7.1.8 Choline chloride with carrier (IFN 7-17-900) is aqueous choline chloride applied to a suitable carrier. It shall be labelled with guarantees for minimum milligrams of choline chloride per kilogram and maximum per cent moisture. It shall also be labelled with a statement indicating the equivalent minimum milligrams of choline per kilogram.
7.1.9 Fish oil (IFN 7-01-965) is oil of fish origin used as a source of vitamins A and D. It shall be labelled with guarantees for minimum international units of vitamin A and minimum international units of vitamin D per kilogram.
7.1.10 Folic acid (or Folacin) (IFN 7-02-066) is N-[4-[[(2-amino-1,4-dihydro-4-oxo-6-pteridinyl)methyl]amino] benzoyl]-L-glutamic acid. It shall be labelled with a guarantee for minimum milligrams of folic acid per kilogram.
7.1.11 Inositol (IFN 7-09-354) is cyclohexanehexol, also referred to as i-inositol or meso-inositol. It shall be labelled with a guarantee for minimum milligrams of inositol per kilogram.
7.1.12 Menadione dimethylpyrimidinol bisulphite (IFN 7-08-102) is the dimethylpyrimidinol salt of menadione. It shall be labelled with a guarantee for minimum milligrams of menadione per kilogram.

7.1.13 Menadione sodium bisulphite (IFN 7-03-077) is the addition product of menadione and sodium bisulphite containing not less than 50% of menadione. It shall be labelled with a guarantee for minimum milligrams of menadione per kilogram.
7.1.14 Menadione sodium bisulphite complex (IFN 7-03-078) is the bisulphite salt of menadione. It shall be labelled with a guarantee for minimum milligrams of menadione per kilogram.
7.1.15 Niacin (or Nicotinic acid) (IFN 7-03-219) is 3-pyridinecarboxylic acid. It shall be labelled with a guarantee for minimum milligrams of niacin per kilogram.
7.1.16 Niacinamide (or Nicotinamide) (IFN 7-03-215) is the amide of nicotinic acid. It shall be labelled with a guarantee for minimum milligrams of niacinamide per kilogram. It shall also be labelled with a statement indicating the equivalent minimum milligrams of niacin per kilogram.
7.1.17 Pyridoxine hydrochloride (IFN 7-03-822) is the hydrochloride of pyridoxine. It shall be labelled with a guarantee for minimum milligrams of pyridoxine hydrochloride per kilogram. It shall also be labelled with a statement indicating the equivalent minimum milligrams of pyridoxine per kilogram.
7.1.18 Riboflavin (IFN 7-03-920) is 7,8-dimethyl-10-(D-ribo-2,3,4,5-tetrahydro xypentyl) isoalloxazine. It shall be labelled with a guarantee for minimum milligrams of riboflavin per kilogram.
7.1.19 Riboflavin-5'-phosphate sodium (IFN 7-17-901) is the sodium salt of the phosphate ester of riboflavin. It shall be labelled with a guarantee for minimum milligrams of riboflavin-5'-phosphate sodium per kilogram. It shall also be labelled with a statement indicating the equivalent minimum milligrams of riboflavin per kilogram.
7.1.20 Thiamine hydrochloride (IFN 7-04-828) is the hydrochloride of thiamine. It shall be labelled with a guarantee for minimum milligrams of thiamine hydrochloride per kilogram.
7.1.21 Thiamine mononitrate (IFN 7-04-829) is the mononitrate of thiamine. It shall be labelled with a guarantee for minimum milligrams of thiamine mononitrate per kilogram. It shall also be labelled with a statement indicating the equivalent minimum milligrams of thiamine hydrochloride per kilogram.
7.1.22 Vitamin B12 (IFN 7-05-146) is cyanocobalamin. It shall be labelled with a guarantee for minimum milligrams of vitamin B12 per kilogram.
7.1.23 Sodium ascorbate (IFN 7-00-433) is the sodium salt of ascorbic acid. It shall be labelled with a guarantee for minimum milligrams of sodium ascorbate per kilogram. It shall also be labelled with a statement indicating the equivalent minimum milligrams of ascorbic acid per kilogram.

Enzymes

Certain enzymes are permitted for addition to organic feed to improve nutrient utilization, not stimulate growth unnaturally. Their use has been shown to be generally beneficial, but not in all studies. Their main benefit is in helping to release more of the nutrients in the feed during digestion, resulting in a lower excretion of undigested nutrients and feed components into the environment. Thus their use helps to reduce environmental pollution and aids environmental sustainability. The main issue is nitrogen and phosphorus contents of animal manure. Excessive nitrogen yields ammonia, which can result in air pollution. Also, soil bacteria can convert nitrogen into nitrate, resulting in soil and water contamination. Undigested phosphorus in manure contributes to phosphorus pollution. A high proportion of undigested fibre in the manure is also undesirable since it increases the bulk of material for land application.

The enzymes permitted for use are usually extracted from edible non-toxic plants, non-pathogenic fungi or non-pathogenic bacteria and may not be produced by genetic engineering technology. They have to be non-toxigenic. They are termed exogenous enzymes to explain that they do not originate in the gut of animals.

Enzymes permitted in animal feeds in the EU are shown in Table 4.8. Various combinations are allowed, as shown in the table. This list does not include enzymes such as α-galactosidase, which are marketed internationally

Table 4.8. Abbreviated list of feed enzymes currently authorized in the European Union (Directive 70/524/EEC and Annex to Directive 82/471/EEC).

Number	Enzyme (alone or in combination)
15	β-Glucanase
2	Phytase
20	β-Xylanase
21	β-Xylanase
25	β-Glucanase and endo-β-xylanase
25 = E 1601	β-Glucanase and β-xylanase
26	β-Glucanase
27	β-Xylanase and β-glucanase
28	Phytase
30	β-Glucanase and β-xylanase
31	β-Xylanase
34	β-Glucanase, β-xylanase and α-amylase
43	β-Xylanase, β-glucanase and α-amylase
46	β-Glucanase, β-xylanase and polygalacturonase
48	α-Amylase and β-glucanase
52	β-Glucanase, β-glucanase (different source) and α-amylase
53	β-Glucanase, β-glucanase (different source), α-amylase and bacillolysin
54	β-Glucanase, β-glucanase (different source), α-amylase and β-xylanase
55	β-Glucanase, β-glucanase (different source), α-amylase and bacillolysin
56	β-Glucanase, β-glucanase (different source), α-amylase and bacillolysin
57	β-Glucanase, β-glucanase (different source), α-amylase and bacillolysin
58	β-Glucanase, β-glucanase (different source), α-amylase and bacillolysin
61	β-Xylanase and β-glucanase
E 1601	β-Glucanase and β-xylanase
E 1602	β-Glucanase, β-glucanase (different source) and β-xylanase
E 1603	β-Glucanase
E 1604	β-Glucanase and β-xylanase
E 1605	β-Xylanase
E 1607	β-Xylanase
E 1608	β-Xylanase and β-glucanase
E 1613	β-Xylanase

Note: some are approved in dry and/or liquid form.

and which may be permitted by other organic agencies. Producers wishing to use enzyme products should check with the local certifying agency for a permitted list.

Examples of enzymes being used in feeds internationally include those outlined below. Often a mixture of enzymes is used, targeted at dealing with the particular profile of substrates in the diet in question. In addition the enzymes have to be stable to processing and pelleting of the diet (Inborr and Bedford, 1993). The role and efficacy of carbohydrase enzymes in pig nutrition have been reviewed by Partridge (2001).

1. Phytase acts on phytate phosphorus in plant materials, releasing more of the contained phosphorus. As a result less phosphorus supplementation is required and a lower amount of phosphorus is excreted in manure (possibly 30%). Simons *et al.* (1990) and Jongbloed *et al.* (1993) reported that adding microbial phytase to diets deficient in available phosphorus enhanced the utilization of dietary phosphorus.

2. β-Glucanase added to a barley-based diet helps break down the barley β-glucan, improving the digestibility of carbohydrate, fat and protein. Graham *et al.* (1988, 1989) and Inborr *et al.* (1993) reported increased digestibility of β-glucans with glucanase supplementation.

3. Xylanase added to a wheat-based diet helps to break down arabinoxylan, an NSP, improving the digestibility of carbohydrate and enhancing fat, protein and starch digestion (Yin *et al.*, 2001). Wolford *et al.* (2001) showed that increasing the inclusion of wheat shorts from 200 to 300 g/kg had a negative effect on digestibility of energy and protein. Xylanase supplementation improved the digestibility of both energy and protein in a linear fashion.

4. α-Galactosidase is added to feed high in plant protein feedstuffs such as soybean meal. These legumes contain oligosaccharides, which cannot be degraded by the endogenous gut enzymes and are fermented in the large intestine causing flatulence. Nutritional constraints in the use of soy products in animals have been reviewed by Baker (2000). α-Galactosidase addition has been shown to improve the digestion of the oligosaccharides in the small intestine (Kim and Baker, 2003).

5. Addition of α-amylase can improve the digestion of starch (Medel *et al.*, 2002) and addition of protease has been shown to improve the digestion of protein (Yin *et al.*, 2001). These applications are of more relevance to very young pigs and are less relevant to organic production since the animals are older when weaned.

Microorganisms

Microorganisms approved for feed use under the EU regulations comprise *Enterococcus faecium* (in various forms) and *Saccharomyces cerevisiae*. Their use as probiotics (as an alternative to antibiotics) is based on the principle of promoting the growth of lactobacilli and reducing the numbers of enteropathogenic bacteria in the gut. Sometimes this principle is referred to as competitive exclusion. Probiotics are probably most relevant to weaned pigs since these young animals have a low immunity to enteric diseases and require time to develop a functional and balanced intestinal microflora for the effective utilization of nutrients and the inhibition of coliform bacteria. Probiotics are probably of most relevance to early-weaned pigs and organic pigs are less likely to be affected by enteric diseases. This aspect will be addressed in more detail in Chapter 7.

Brewer's yeast

Brewer's yeast (*S. cerevisiae*) is permitted as a feed ingredient in organic diets. This by-product has been used traditionally in animal diets as a source of nutrients. For instance, Evans (1952) showed that when a basal cereal diet was supplemented with 70 g white fishmeal or 150 g dried brewer's yeast per kg to give a total of 120 g digestible CP per kg, the diet supplemented with dried brewer's yeast resulted in higher live-weight gain, feed conversion efficiency and nitrogen. However, acceptability of the diet was lower with more than 120 g yeast/kg. In subsequent work pigs were fed to 70 kg live weight on diets supplemented with 90 and 120 g dried brewer's yeast or 70 g white fishmeal per kg. Live-weight increase and feed conversion efficiency did not differ significantly among the groups. Evans (1952) concluded that as a protein supplement to a basal diet of barley, fine bran and lucerne meal, dried brewer's yeast was as good as white fishmeal.

Inactivated yeast should be used for animal feeding since live yeast may grow in the intestinal tract and compete for nutrients.

Liquid yeast has also been used in pig diets (Mazzocco and Bolla, 1989). In this study a diet containing liquid brewer's yeast at 100 g/kg was given pigs initially from about 24 kg to slaughter at 135 kg. Compared with a control group fed a diet containing soybean oil meal, pigs given liquid brewer's yeast-containing diets had greater daily gains: 880 versus 743 g/day for males and 797 versus 788 g/day for females. Feed conversion efficiency was similar for both groups. Carcass quality was not affected by inclusion of liquid brewer's yeast; however, yield of ham was higher in pigs given the yeast-containing diet.

Other yeasts have been included in pig diets and may be acceptable as ingredients for organic production. Some countries producing sugarcane and molasses use these as substrates for yeast production as a protein supplement for pig diets, with good results.

For instance, Moreira *et al*. (2002) conducted research to evaluate the potential use of spray-dried sugarcane yeast *Saccharomyces* spp. for use in diets for growing-finishing pigs. The piglets were fed *ad libitum* with diets containing increasing levels of yeast (0, 70, 140 and 210 g/kg). It was found that inclusion of yeast in the grower phase (to 60 kg) decreased the feed:gain ratio, with no effects on feed intake and daily live-weight gain. In the finishing phase (to 86 kg) and in the total trial phase, no performance differences were noted. The results suggested that up to 210 g/kg could be used in grower-finisher pig diets without impairing daily live-weight gain.

Yeasts have also been used to detoxify the diet of mycotoxins. Modified yeast cell wall mannanoligosaccharide (MOS) has been reported to effectively bind aflatoxin, and to bind ochratoxin and the fusariotoxins to a lesser degree. This product has advantages over other binding agents in that it does not bind vitamins or minerals (Girish and Devegowda, 2006).

Tables of Nutrient Contents of Feedstuffs

Tables 4.9–4.57 present data on average values of energy and nutrients for a range of feedstuffs likely to be used in organic pig feeding (as-fed basis). Each feedstuff is listed under its IFN (Harris, 1980), the definitions of the feedstuffs being those of the Association of American Feed Control Officials (AAFCO, 2005) or the Canadian Food Inspection Agency (CFIA, 2015). Table 4.58 gives suggested maximum inclusion rates for organic pig diets.

Table 4.9. Barley (IFN 4-00-549).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	890.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3090	Calcium	0.3
Digestible energy (MJ/kg)	12.93	Phosphorus (total)	3.8
Metabolizable energy (kcal/kg)	2966	Phosphorus (available)	1.1
Metabolizable energy (MJ/kg)	12.41	Chloride	1.2
Crude fibre (g/kg)	44.1	Magnesium	1.2
Neutral-detergent fibre (g/kg)	175.4	Potassium	4.4
Acid-detergent fibre (g/kg)	45.4	Sodium	0.07
Crude fat (g/kg)	18.56	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	8.8	Copper	2.35
Crude protein (g/kg)	102.7	Iodine	0.35
Amino acids (g/kg)		Iron	62.0
Arginine	5.2	Manganese	19.4
Histidine	2.2	Selenium	0.19
Isoleucine	3.5	Zinc	23.9
Leucine	6.6	Vitamins	
Lysine	3.8	β-Carotene (mg/kg)	4.1
Methionine (Met)	2.1	Vitamin A (IU/kg)	1095
Met + cystine	4.2	Vitamin E (IU/kg)	7.4
Phenylalanine (Phe)	4.5	Vitamins (mg/kg)	
Phe + tyrosine	7.9	Biotin	0.14
Threonine	3.4	Choline	1034
Tryptophan	1.0	Folacin	0.31
Valine	4.8	Niacin	55.0
Available lysine	2.9	Pantothenic acid	8.0
		Pyridoxine	5.0
		Riboflavin	1.8
		Thiamin	4.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The entire seed of the barley plant (CFIA, 2015).

Table 4.10. Cabbage raw (IFN 2-01-046).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	81.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	242	Calcium	0.67
Digestible energy (MJ/kg)	1.0	Phosphorus (total)	0.15
Metabolizable energy (kcal/kg)	232	Phosphorus (available)	0.05
Metabolizable energy (MJ/kg)	0.97	Chloride	0.43
Crude fibre (g/kg)	11.6	Magnesium	0.12
Neutral-detergent fibre (g/kg)	14.1	Potassium	2.88
Acid-detergent fibre (g/kg)	11.5	Sodium	0.12
Crude fat (g/kg)	1.2	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.26	Copper	0.23
Crude protein (g/kg)	18.6	Iodine	0.06
Amino acids (g/kg)		Iron	5.9
Arginine	0.75	Manganese	1.59
Histidine	0.34	Selenium	0.01
Isoleucine	0.43	Zinc	1.8
Leucine	0.60	Vitamins	
Lysine	0.67	β-Carotene (mg/kg)	0.9
Methionine (Met)	0.14	Vitamin A (IU/kg)	235.0
Met + cystine	0.28	Vitamin E (IU/kg)	1.5
Phenylalanine (Phe)	0.45	Vitamins (mg/kg)	
Phe + tyrosine	0.69	Biotin	NA
Threonine	0.44	Choline	NA
Tryptophan	0.15	Folacin	0.43
Valine	0.65	Niacin	3.0
Available lysine	NA	Pantothenic acid	1.4
		Pyridoxine	0.96
		Riboflavin	0.4
		Thiamin	0.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The aerial part of the *Brassica oleracea* (*Capitata* group) plant (not defined by the Association of American Feed Control Officials or the Canadian Food Inspection Agency).

Table 4.11. Canola seed cooked (IFN 5-06-597).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	940.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	4032	Calcium	2.6
Digestible energy (MJ/kg)	16.9	Phosphorus (total)	6.0
Metabolizable energy (kcal/kg)	3870	Phosphorus (available)	1.8
Metabolizable energy (MJ/kg)	16.2	Chloride	0.52
Crude fibre (g/kg)	68.6	Magnesium	3.0
Neutral-detergent fibre (g/kg)	259.2	Potassium	5.0
Acid-detergent fibre (g/kg)	129.1	Sodium	0.2
Crude fat (g/kg)	379.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	109.9	Copper	2.8
Crude protein (g/kg)	201.6	Iodine	NA
Amino acids (g/kg)		Iron	88.0
Arginine	11.3	Manganese	32.4
Histidine	5.7	Selenium	0.5
Isoleucine	8.0	Zinc	31.1
Leucine	13.3	Vitamins	
Lysine	11.7	β-Carotene (mg/kg)	NA
Methionine (Met)	3.3	Vitamin A (IU/kg)	NA
Met + cystine	6.7	Vitamin E (IU/kg)	9.1
Phenylalanine (Phe)	8.5	Vitamins (mg/kg)	
Phe + tyrosine	13.7	Biotin	0.67
Threonine	8.2	Choline	4185
Tryptophan	2.3	Folacin	1.4
Valine	9.5	Niacin	100.0
Available lysine	8.9	Pantothenic acid	5.9
		Pyridoxine	4.5
		Riboflavin	3.6
		Thiamin	3.2
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The entire seed of the species *Brassica napus* or *Brassica campestris*, the oil component of which contains less than 2% erucic acid and the solid component of which contains less than 30 μmol of any one or any mixture of 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3-butenyl glucosinolate and 2-hydroxy-4-pentenyl glucosinolate per g of air-dry, oil-free solid (gas–liquid chromatography method of the Canadian Grain Commission) (CFIA, 2015).

Table 4.12. Canola meal expeller (IFN 5-06-870).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	940.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3437	Calcium	7.1
Digestible energy (MJ/kg)	14.4	Phosphorus (total)	12.0
Metabolizable energy (kcal/kg)	3200	Phosphorus (available)	2.9
Metabolizable energy (MJ/kg)	13.81	Chloride	0.5
Crude fibre (g/kg)	95.6	Magnesium	4.6
Neutral-detergent fibre (g/kg)	226.6	Potassium	11.5
Acid-detergent fibre (g/kg)	145.6	Sodium	0.05
Crude fat (g/kg)	148.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	14.8	Copper	5.5
Crude protein (g/kg)	309.0	Iodine	0.6
Amino acids (g/kg)		Iron	169.0
Arginine	21.3	Manganese	37.3
Histidine	9.0	Selenium	0.03
Isoleucine	13.9	Zinc	53.2
Leucine	23.8	Vitamins	
Lysine	19.5	β-Carotene (mg/kg)	NA
Methionine (Met)	7.4	Vitamin A (IU/kg)	NA
Met + cystine	13.9	Vitamin E (IU/kg)	18.8
Phenylalanine (Phe)	13.9	Vitamins (mg/kg)	
Phe + tyrosine	25.6	Biotin	0.9
Threonine	15.1	Choline	6532
Tryptophan	5.3	Folacin	2.2
Valine	17.6	Niacin	155.0
Available lysine	14.1	Pantothenic acid	8.0
		Pyridoxine	NA
		Riboflavin	3.0
		Thiamin	1.8
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The residual product obtained after extraction of most of the oil from canola seeds by a mechanical extraction process (not defined by the Association of American Feed Control Officials or the Canadian Food Inspection Agency).

Table 4.13. Cassava (manioc) (IFN 4-01-152).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	880.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3385	Calcium	2.2
Digestible energy (MJ/kg)	14.16	Phosphorus (total)	1.5
Metabolizable energy (kcal/kg)	3330	Phosphorus (available)	0.7
Metabolizable energy (MJ/kg)	13.93	Chloride	NA
Crude fibre (g/kg)	NA	Magnesium	NA
Neutral-detergent fibre (g/kg)	NA	Potassium	NA
Acid-detergent fibre (g/kg)	NA	Sodium	NA
Crude fat (g/kg)	5.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	NA	Copper	NA
Crude protein (g/kg)	33.0	Iodine	NA
Amino acids (g/kg)		Iron	NA
Arginine	NA	Manganese	NA
Histidine	NA	Selenium	NA
Isoleucine	NA	Zinc	NA
Leucine	NA	Vitamins	
Lysine	0.7	β-Carotene (mg/kg)	NA
Methionine (Met)	0.2	Vitamin A (IU/kg)	NA
Met + cystine	0.4	Vitamin E (IU/kg)	NA
Phenylalanine (Phe)	NA	Vitamins (mg/kg)	
Phe + tyrosine	NA	Biotin	NA
Threonine	NA	Choline	NA
Tryptophan	NA	Folacin	NA
Valine	NA	Niacin	NA
Available lysine	0.4	Pantothenic acid	NA
		Pyridoxine	NA
		Riboflavin	NA
		Thiamin	NA
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	NA

IFN, International Feed Number; NA, no data available.
[a]The whole root of cassava (or tapioca) chipped mechanically into small pieces and sun-dried. It must be free of sand and other debris except for that which occurs unavoidably as a result of good harvesting practices. The levels of HCN equivalent (HCN, linamarin and cyanohydrins combined) must not exceed 50 mg/kg in the complete feed. It is intended for use as an energy feed in livestock feeds at a level not to exceed 40% of pig complete feeds (CFIA, 2015).

Table 4.14. Cottonseed meal expeller (IFN 5-01-609).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	920.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	2945	Calcium	2.3
Digestible energy (MJ/kg)	12.32	Phosphorus (total)	10.3
Metabolizable energy (kcal/kg)	2690	Phosphorus (available)	3.4
Metabolizable energy (MJ/kg)	11.25	Chloride	0.4
Crude fibre (g/kg)	119.0	Magnesium	5.2
Neutral-detergent fibre (g/kg)	257.0	Potassium	13.4
Acid-detergent fibre (g/kg)	180.0	Sodium	0.4
Crude fat (g/kg)	61.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	31.5	Copper	19.0
Crude protein (g/kg)	424.0	Iodine	0.1
Amino acids (g/kg)		Iron	160.0
Arginine	42.6	Manganese	23.0
Histidine	11.1	Selenium	0.9
Isoleucine	12.9	Zinc	64.0
Leucine	24.5	Vitamins	
Lysine	16.5	β-Carotene (mg/kg)	NA
Methionine (Met)	6.7	Vitamin A (IU/kg)	NA
Met + cystine	13.6	Vitamin E (IU/kg)	35.0
Phenylalanine (Phe)	19.7	Vitamins (mg/kg)	
Phe + tyrosine	32.0	Biotin	0.3
Threonine	13.4	Choline	2753
Tryptophan	5.4	Folacin	1.65
Valine	17.6	Niacin	38.0
Available lysine	11.6	Pantothenic acid	10.0
		Pyridoxine	5.3
		Riboflavin	5.1
		Thiamin	6.4
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The residual product obtained after extraction of most of the oil from cottonseed by a mechanical extraction process (CFIA, 2015).

Table 4.15. Distiller's grains with solubles, dried (IFN 5-02-843).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	930.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3200	Calcium	2.0
Digestible energy (MJ/kg)	13.39	Phosphorus (total)	7.7
Metabolizable energy (kcal/kg)	2820	Phosphorus (available)	6.2
Metabolizable energy (MJ/kg)	11.8	Chloride	2.0
Crude fibre (g/kg)	78.0	Magnesium	1.9
Neutral-detergent fibre (g/kg)	346.0	Potassium	8.4
Acid-detergent fibre (g/kg)	163.0	Sodium	2.5
Crude fat (g/kg)	84.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	21.5	Copper	57.0
Crude protein (g/kg)	277.0	Iodine	NA
Amino acids (g/kg)		Iron	257.0
Arginine	11.3	Manganese	24.0
Histidine	6.9	Selenium	0.39
Isoleucine	10.3	Zinc	80.0
Leucine	25.7	Vitamins	
Lysine	6.2	β-Carotene (mg/kg)	3.5
Methionine (Met)	5.0	Vitamin A (IU/kg)	910.0
Met + cystine	10.2	Vitamin E (IU/kg)	NA
Phenylalanine (Phe)	13.4	Vitamins (mg/kg)	
Phe + tyrosine	21.7	Biotin	0.78
Threonine	9.4	Choline	2637
Tryptophan	2.5	Folacin	0.9
Valine	1.3	Niacin	75.0
Available lysine	3.0	Pantothenic acid	14.0
		Pyridoxine	8.0
		Riboflavin	8.6
		Thiamin	2.9
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The product obtained after the removal of ethanol by distillation from the yeast fermentation of a grain or a grain mixture by condensing and drying at least 75% of the solids of the resultant whole stillage by methods employed in the grain distilling industry. The predominating grain shall be declared as the first word in the name (AAFCO, 2005).

Table 4.16. Faba beans (IFN 5-09-262).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	870.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3245	Calcium	0.9
Digestible energy (MJ/kg)	13.58	Phosphorus (total)	3.6
Metabolizable energy (kcal/kg)	3045	Phosphorus (available)	1.4
Metabolizable energy (MJ/kg)	12.74	Chloride	0.7
Crude fibre (g/kg)	71.4	Magnesium	1.3
Neutral-detergent fibre (g/kg)	126.0	Potassium	11.3
Acid-detergent fibre (g/kg)	75.2	Sodium	0.1
Crude fat (g/kg)	17.2	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	5.8	Copper	6.4
Crude protein (g/kg)	254.0	Iodine	NA
Amino acids (g/kg)		Iron	47.8
Arginine	23.9	Manganese	12.2
Histidine	6.7	Selenium	0.09
Isoleucine	10.3	Zinc	49.0
Leucine	18.9	Vitamins	
Lysine	16.5	β-Carotene (mg/kg)	NA
Methionine (Met)	2.4	Vitamin A (IU/kg)	NA
Met + cystine	5.2	Vitamin E (IU/kg)	0.8
Phenylalanine (Phe)	10.9	Vitamins (mg/kg)	
Phe + tyrosine	20.3	Biotin	0.09
Threonine	9.0	Choline	1670
Tryptophan	2.2	Folacin	4.23
Valine	11.9	Niacin	26.0
Available lysine	13.3	Pantothenic acid	3.0
		Pyridoxine	3.66
		Riboflavin	2.9
		Thiamin	5.5
		Vitamins (µg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The entire seed of the faba bean plant *Vicia faba* (CFIA, 2015).

Table 4.17. Flaxseed (IFN 5-30-286).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	890.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	4604	Calcium	2.8
Digestible energy (MJ/kg)	19.3	Phosphorus (total)	4.4
Metabolizable energy (kcal/kg)	4420	Phosphorus (available)	1.2
Metabolizable energy (MJ/kg)	18.5	Chloride	0.3
Crude fibre (g/kg)	94.8	Magnesium	3.9
Neutral-detergent fibre (g/kg)	262.7	Potassium	9.2
Acid-detergent fibre (g/kg)	129.8	Sodium	0.4
Crude fat (g/kg)	286.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	52.0	Copper	12.8
Crude protein (g/kg)	196.7	Iodine	NA
Amino acids (g/kg)		Iron	86.0
Arginine	18.3	Manganese	18.9
Histidine	4.4	Selenium	0.1
Isoleucine	7.9	Zinc	53.0
Leucine	11.5	Vitamins	
Lysine	7.8	β-Carotene (mg/kg)	NA
Methionine (Met)	2.8	Vitamin A (IU/kg)	NA
Met + cystine	6.2	Vitamin E (IU/kg)	NA
Phenylalanine (Phe)	9.1	Vitamins (mg/kg)	
Phe + tyrosine	13.6	Biotin	0.06
Threonine	7.2	Choline	NA
Tryptophan	2.0	Folacin	1.12
Valine	9.1	Niacin	32.1
Available lysine	6.4	Pantothenic acid	5.7
		Pyridoxine	6.1
		Riboflavin	2.3
		Thiamin	5.3
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0

IFN, International Feed Number; NA, no data available.
[a]The entire seed of the linseed plant (*Linum usitatissimum*), (CFIA, 2015).

Table 4.18. Flaxseed (linseed) meal expeller (IFN 5-30-287).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	910.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3381	Calcium	2.6
Digestible energy (MJ/kg)	14.15	Phosphorus (total)	5.9
Metabolizable energy (kcal/kg)	2761	Phosphorus (available)	1.3
Metabolizable energy (MJ/kg)	11.55	Chloride	0.4
Crude fibre (g/kg)	64.8	Magnesium	4.0
Neutral-detergent fibre (g/kg)	178.2	Potassium	9.3
Acid-detergent fibre (g/kg)	87.3	Sodium	0.7
Crude fat (g/kg)	115.2	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	21.0	Copper	17.4
Crude protein (g/kg)	345.6	Iodine	NA
Amino acids (g/kg)		Iron	167.4
Arginine	32.8	Manganese	28.3
Histidine	7.3	Selenium	0.1
Isoleucine	14.2	Zinc	64.7
Leucine	19.4	Vitamins	
Lysine	10.4	β-Carotene (mg/kg)	0.0
Methionine (Met)	6.6	Vitamin A (IU/kg)	0.0
Met + cystine	10.1	Vitamin E (IU/kg)	8.0
Phenylalanine (Phe)	15.6	Vitamins (mg/kg)	
Phe + tyrosine	24.2	Biotin	0.33
Threonine	10.4	Choline	1780
Tryptophan	5.0	Folacin	2.8
Valine	16.9	Niacin	37.0
Available lysine	8.5	Pantothenic acid	14.3
		Pyridoxine	5.5
		Riboflavin	3.2
		Thiamin	4.2
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The product obtained by grinding the cake or chips which remain after removal of most of the oil from flaxseed by a mechanical extraction process. It must contain no more than 100 g fibre/kg (AAFCO, 2005).

Table 4.19. Grass meal dehydrated (IFN 1-02-211).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	917.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	2130	Calcium	6.3
Digestible energy (MJ/kg)	8.91	Phosphorus (total)	3.48
Metabolizable energy (kcal/kg)	2040	Phosphorus (available)	NA
Metabolizable energy (MJ/kg)	8.54	Chloride	8.0
Crude fibre (g/kg)	208.7	Magnesium	1.74
Neutral-detergent fibre (g/kg)	524.9	Potassium	25.1
Acid-detergent fibre (g/kg)	253.7	Sodium	2.84
Crude fat (g/kg)	34.2	Trace minerals (mg/kg)	
Linoleic acid (g/kg)		Copper	6.7
Crude protein (g/kg)	182.2	Iodine	0.14
Amino acids (g/kg)		Iron	NA
Arginine	7.5	Manganese	53.0
Histidine	2.7	Selenium	0.05
Isoleucine	5.6	Zinc	19.0
Leucine	12.1	Vitamins	
Lysine	7.1	β-Carotene (mg/kg)	35.8
Methionine (Met)	3.1	Vitamin A (IU/kg)	9559
Met + cystine	5.0	Vitamin E (IU/kg)	150.0
Phenylalanine (Phe)	7.1	Vitamins (mg/kg)	
Phe + tyrosine	11.6	Biotin	0.22
Threonine	6.2	Choline	1470
Tryptophan	3.1	Folacin	NA
Valine	7.0	Niacin	74.0
Available lysine	NA	Pantothenic acid	15.4
		Pyridoxine	11.7
		Riboflavin	15.5
		Thiamin	12.6
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The product of drying and grinding grass that has been cut before formation of the seed. If a species name is used, the produce must correspond thereto (AAFCO, 2005).

Table 4.20. Herring meal (IFN 5-02-000).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	925.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3960	Calcium	24.0
Digestible energy (MJ/kg)	16.57	Phosphorus (total)	17.6
Metabolizable energy (kcal/kg)	3260	Phosphorus (available)	17.0
Metabolizable energy (MJ/kg)	13.64	Chloride	11.2
Crude fibre (g/kg)	0.0	Magnesium	1.8
Neutral-detergent fibre (g/kg)	0.0	Potassium	10.1
Acid-detergent fibre (g/kg)	0.0	Sodium	6.1
Crude fat (g/kg)	92.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	1.5	Copper	6.0
Crude protein (g/kg)	681.0	Iodine	2.0
Amino acids (g/kg)		Iron	181.0
Arginine	40.1	Manganese	8.0
Histidine	15.2	Selenium	1.93
Isoleucine	29.1	Zinc	132.0
Leucine	52.0	Vitamins	
Lysine	54.6	β-Carotene (mg/kg)	0.0
Methionine (Met)	20.4	Vitamin A (IU/kg)	0.0
Met + cystine	28.2	Vitamin E (IU/kg)	15.0
Phenylalanine (Phe)	27.5	Vitamins (mg/kg)	
Phe + tyrosine	49.3	Biotin	0.13
Threonine	30.2	Choline	5306
Tryptophan	7.4	Folacin	0.37
Valine	34.6	Niacin	93.0
Available lysine	48.6	Pantothenic acid	17.0
		Pyridoxine	4.8
		Riboflavin	9.9
		Thiamin	0.4
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	403.0

IFN, International Feed Number; NA, no data available.
[a]Fishmeal is the clean, dried, ground tissue of undecomposed whole fish or fish cuttings, either or both, with or without the extraction of part of the oil. If it bears a name descriptive of its type, it must correspond thereto (AAFCO, 2005).

Table 4.21. Hominy feed (IFN 4-03-011).[a]

Component	Amount	Component	Am ount
Dry matter (g/kg)	900.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3355	Calcium	0.5
Digestible energy (MJ/kg)	14.04	Phosphorus (total)	4.3
Metabolizable energy (kcal/kg)	3210	Phosphorus (available)	0.6
Metabolizable energy (MJ/kg)	13.43	Chloride	0.7
Crude fibre (g/kg)	49.0	Magnesium	2.4
Neutral-detergent fibre (g/kg)	285	Potassium	6.1
Acid-detergent fibre (g/kg)	81.0	Sodium	0.8
Crude fat (g/kg)	67.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	29.7	Copper	13.0
Crude protein (g/kg)	103.0	Iodine	NA
Amino acids (g/kg)		Iron	67.0
Arginine	5.6	Manganese	15.0
Histidine	2.8	Selenium	0.1
Isoleucine	3.6	Zinc	NA
Leucine	9.8	Vitamins	
Lysine	3.8	β-Carotene (mg/kg)	9.0
Methionine (Met)	1.8	Vitamin A (IU/kg)	2340
Met + cystine	3.6	Vitamin E (IU/kg)	6.5
Phenylalanine (Phe)	4.3	Vitamins (mg/kg)	
Phe + tyrosine	8.3	Biotin	0.13
Threonine	4.0	Choline	1155
Tryptophan	1.0	Folacin	0.21
Valine	5.2	Niacin	47.0
Available lysine	3.0	Pantothenic acid	8.2
		Pyridoxine	11.0
		Riboflavin	2.1
		Thiamin	8.1
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]A mixture of maize bran, maize germ and part of the starchy portion of either white or yellow maize kernels or a mixture thereof, as produced in the manufacture of pearl hominy, hominy grits or table meal; must contain not less than 40 g crude fat/kg. If prefixed with the word 'white' or 'yellow', the product must correspond thereto (AAFCO, 2005).

Table 4.22. Kelp meal (seaweed) dehydrated or dried (IFN 1-08-073).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	930.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	489	Calcium	1.68
Digestible energy (MJ/kg)	2.05	Phosphorus (total)	0.42
Metabolizable energy (kcal/kg)	465	Phosphorus (available)	NA
Metabolizable energy (MJ/kg)	1.94	Chloride	1.2
Crude fibre (g/kg)	239.0	Magnesium	1.21
Neutral-detergent fibre (g/kg)	NA	Potassium	0.9
Acid-detergent fibre (g/kg)	100.0	Sodium	0.8
Crude fat (g/kg)	30.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	1.01	Copper	45.0
Crude protein (g/kg)	16.8	Iodine	3500
Amino acids (g/kg)		Iron	444.0
Arginine	0.65	Manganese	2.0
Histidine	0.24	Selenium	0.4
Isoleucine	0.76	Zinc	12.3
Leucine	0.83	Vitamins	
Lysine	0.82	β-Carotene (mg/kg)	0.7
Methionine (Met)	0.25	Vitamin A (IU/kg)	186.9
Met + cystine	1.23	Vitamin E (IU/kg)	8.7
Phenylalanine (Phe)	0.43	Vitamins (mg/kg)	
Phe + tyrosine	0.69	Biotin	0.09
Threonine	0.55	Choline	1670
Tryptophan	0.48	Folacin	1.65
Valine	0.72	Niacin	26.0
Available lysine	NA	Pantothenic acid	3.0
		Pyridoxine	0.02
		Riboflavin	2.9
		Thiamin	5.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	50.0

IFN, International Feed Number; NA, no data available.
[a]The product resulting from drying and grinding non-toxic macroscopic marine algae (marine plants) of the families *Gelidiaceae*, *Gigartinaceae*, *Gracilariaceae*, *Solieriaceae*, *Palmariaceae*, *Bangiaceae*, *Laminariaceae*, *Lessoniaceae*, *Alariaceae*, *Fucaceae*, *Sargassaceae*, *Monostromataceae* and *Ulvaceae* (CFIA, 2015).

Table 4.23. Lucerne (alfalfa) dehydrated (IFN 1-00-023).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	920.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	1582	Calcium	12.1
Digestible energy (MJ/kg)	6.62	Phosphorus (total)	3.4
Metabolizable energy (kcal/kg)	1520	Phosphorus (available)	1.6
Metabolizable energy (MJ/kg)	6.4	Chloride	4.7
Crude fibre (g/kg)	259.4	Magnesium	2.8
Neutral-detergent fibre (g/kg)	458.2	Potassium	14.7
Acid-detergent fibre (g/kg)	296.2	Sodium	0.6
Crude fat (g/kg)	26.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	3.5	Copper	22.1
Crude protein (g/kg)	154.0	Iodine	NA
Amino acids (g/kg)		Iron	333.0
Arginine	6.4	Manganese	62.6
Histidine	3.4	Selenium	0.11
Isoleucine	6.2	Zinc	36.8
Leucine	10.9	Vitamins	
Lysine	6.7	β-Carotene (mg/kg)	170.0
Methionine (Met)	2.3	Vitamin A (IU/kg)	45,390
Met + cystine	3.9	Vitamin E (IU/kg)	49.8
Phenylalanine (Phe)	7.6	Vitamins (mg/kg)	
Phe + tyrosine	12.6	Biotin	0.54
Threonine	6.3	Choline	1,401
Tryptophan	2.2	Folacin	4.36
Valine	7.8	Niacin	38.0
Available lysine	3.1	Pantothenic acid	29.0
		Pyridoxine	6.5
		Riboflavin	13.6
		Thiamin	3.4
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The aerial portion of the lucerne plant which has been dried by thermal means and finely ground (AAFCO, 2005).

Table 4.24. Lucerne (alfalfa) sun-cured (IFN 1-00-059).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	907.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	1,740	Calcium	12.7
Digestible energy (MJ/kg)	7.28	Phosphorus (total)	2.0
Metabolizable energy (kcal/kg)	1,351	Phosphorus (available)	1.8
Metabolizable energy (MJ/kg)	5.65	Chloride	3.4
Crude fibre (g/kg)	207.0	Magnesium	2.9
Neutral-detergent fibre (g/kg)	368.0	Potassium	22.7
Acid-detergent fibre (g/kg)	290.0	Sodium	1.3
Crude fat (g/kg)	32.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	4.3	Copper	10.0
Crude protein (g/kg)	162.0	Iodine	NA
Amino acids (g/kg)		Iron	173.0
Arginine	7.3	Manganese	27.0
Histidine	3.4	Selenium	0.49
Isoleucine	6.0	Zinc	22.0
Leucine	10.7	Vitamins	
Lysine	8.1	β-Carotene (mg/kg)	145.8
Methionine (Met)	1.9	Vitamin A (IU/kg)	38,929
Met + cystine	5.0	Vitamin E (IU/kg)	200.0
Phenylalanine (Phe)	7.1	Vitamins (mg/kg)	
Phe + tyrosine	11.9	Biotin	0.005
Threonine	6.0	Choline	918.9
Tryptophan	1.8	Folacin	0.24
Valine	7.9	Niacin	8.2
Available lysine	3.73	Pantothenic acid	28.0
		Pyridoxine	4.4
		Riboflavin	15.0
		Thiamin	4.2
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The aerial portion of the lucerne plant which has been dried by solar means and finely or coarsely ground (AAFCO, 2005).

Table 4.25. Lupinseed meal sweet white (IFN 5-27-717).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	858.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3226	Calcium	2.7
Digestible energy (MJ/kg)	13.5	Phosphorus (total)	4.7
Metabolizable energy (kcal/kg)	3100	Phosphorus (available)	1.7
Metabolizable energy (MJ/kg)	13.0	Chloride	0.3
Crude fibre (g/kg)	126.0	Magnesium	0.9
Neutral-detergent fibre (g/kg)	209.0	Potassium	9.0
Acid-detergent fibre (g/kg)	147.0	Sodium	0.1
Crude fat (g/kg)	53.2	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	35.6	Copper	5.4
Crude protein (g/kg)	311.0	Iodine	NA
Amino acids (g/kg)		Iron	71.0
Arginine	33.3	Manganese	48.9
Histidine	7.7	Selenium	0.07
Isoleucine	12.1	Zinc	27.4
Leucine	19.9	Vitamins	
Lysine	14.0	β-Carotene (mg/kg)	NA
Methionine (Met)	2.2	Vitamin A (IU/kg)	NA
Met + cystine	5.3	Vitamin E (IU/kg)	8.0
Phenylalanine (Phe)	11.2	Vitamins (mg/kg)	
Phe + tyrosine	22.1	Biotin	0.05
Threonine	10.0	Choline	NA
Tryptophan	2.3	Folacin	3.6
Valine	11.5	Niacin	21.9
Available lysine	11.6	Pantothenic acid	7.5
		Pyridoxine	3.6
		Riboflavin	2.2
		Thiamin	6.4
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The ground whole seed of the species *Lupinus albus*, *Lupinus angustifolius* or *Lupinus luteus*. It has to contain less than 0.3 g total alkaloids per kg. The species of seed must be listed after the name 'Sweet lupin seeds, ground' (CFIA, 2015).

Table 4.26. Maize yellow (IFN 4-02-935).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	890.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3525	Calcium	0.3
Digestible energy (MJ/kg)	14.75	Phosphorus (total)	2.8
Metabolizable energy (kcal/kg)	3420	Phosphorus (available)	0.4
Metabolizable energy (MJ/kg)	14.31	Chloride	0.5
Crude fibre (g/kg)	26.0	Magnesium	1.2
Neutral-detergent fibre (g/kg)	96.0	Potassium	3.3
Acid-detergent fibre (g/kg)	28.0	Sodium	0.2
Crude fat (g/kg)	39.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	19.2	Copper	3.0
Crude protein (g/kg)	83.0	Iodine	0.05
Amino acids (g/kg)		Iron	29.0
Arginine	3.7	Manganese	7.0
Histidine	2.3	Selenium	0.07
Isoleucine	2.8	Zinc	18.0
Leucine	9.9	Vitamins	
Lysine	2.6	β-Carotene (mg/kg)	17.0
Methionine (Met)	1.7	Vitamin A (IU/kg)	4540
Met + cystine	3.8	Vitamin E (IU/kg)	8.3
Phenylalanine (Phe)	3.9	Vitamins (mg/kg)	
Phe + tyrosine	6.4	Biotin	0.06
Threonine	2.9	Choline	620.0
Tryptophan	0.6	Folacin	0.15
Valine	3.9	Niacin	24.0
Available lysine	2.0	Pantothenic acid	6.0
		Pyridoxine	5.0
		Riboflavin	1.2
		Thiamin	3.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The whole yellow maize kernel (CFIA, 2015).

Table 4.27. Menhaden fishmeal (IFN 5-02-009).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	920.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3770	Calcium	52.1
Digestible energy (MJ/kg)	15.77	Phosphorus (total)	30.4
Metabolizable energy (kcal/kg)	3360	Phosphorus (available)	28.0
Metabolizable energy (MJ/kg)	14.06	Chloride	5.5
Crude fibre (g/kg)	0.0	Magnesium	1.6
Neutral-detergent fibre (g/kg)	0.0	Potassium	7.0
Acid-detergent fibre (g/kg)	0.0	Sodium	4.0
Crude fat (g/kg)	94.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	1.2	Copper	11.0
Crude protein (g/kg)	623.0	Iodine	2.0
Amino acids (g/kg)		Iron	440.0
Arginine	36.6	Manganese	37.0
Histidine	17.8	Selenium	2.1
Isoleucine	25.7	Zinc	147.0
Leucine	45.4	Vitamins	
Lysine	48.1	β-Carotene (mg/kg)	0.0
Methionine (Met)	17.7	Vitamin A (IU/kg)	0.0
Met + cystine	23.4	Vitamin E (IU/kg)	5.0
Phenylalanine (Phe)	25.1	Vitamins (mg/kg)	
Phe + tyrosine	45.5	Biotin	0.13
Threonine	26.4	Choline	3056
Tryptophan	6.6	Folacin	0.37
Valine	30.3	Niacin	55.0
Available lysine	42.8	Pantothenic acid	9.0
		Pyridoxine	4.0
		Riboflavin	4.9
		Thiamin	0.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	143.0

IFN, International Feed Number.
[a]Fish meal is the clean, dried, ground tissue of undecomposed whole fish or fish cuttings, either or both, with or without the extraction of part of the oil. If it bears a name descriptive of its type, it must correspond thereto (AAFCO, 2005).

Table 4.28. Milk skimmed fluid (IFN 5-01-170).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	91.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	380	Calcium	1.2
Digestible energy (MJ/kg)	1.59	Phosphorus (total)	1.0
Metabolizable energy (kcal/kg)	350	Phosphorus (available)	1.0
Metabolizable energy (MJ/kg)	1.46	Chloride	1.0
Crude fibre (g/kg)	0.0	Magnesium	0.1
Neutral-detergent fibre (g/kg)	0.0	Potassium	1.5
Acid-detergent fibre (g/kg)	0.0	Sodium	0.6
Crude fat (g/kg)	0.9	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.3	Copper	0.04
Crude protein (g/kg)	3.5	Iodine	0.03
Amino acids (g/kg)		Iron	1.0
Arginine	1.2	Manganese	0.1
Histidine	0.9	Selenium	0.05
Isoleucine	1.9	Zinc	4.0
Leucine	3.4	Vitamins	
Lysine	2.7	β-Carotene (mg/kg)	0.0
Methionine (Met)	0.7	Vitamin A (IU/kg)	70.0
Met + cystine	1.0	Vitamin E (IU/kg)	0.4
Phenylalanine (Phe)	1.8	Vitamins (mg/kg)	
Phe + tyrosine	3.3	Biotin	NA
Threonine	1.5	Choline	135.0
Tryptophan	0.5	Folacin	0.05
Valine	2.3	Niacin	0.88
Available lysine	2.7	Pantothenic acid	3.29
		Pyridoxine	0.4
		Riboflavin	1.4
		Thiamin	0.36
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	3.8

IFN, International Feed Number; NA, no data available.
[a]De-fatted milk of cattle (not defined by the Association of American Feed Control Officials or the Canadian Food Inspection Agency).

Table 4.29. Milk skimmed dehydrated (IFN 5-01-175).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	960.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3980	Calcium	13.1
Digestible energy (MJ/kg)	16.66	Phosphorus (total)	10.0
Metabolizable energy (kcal/kg)	3715	Phosphorus (available)	9.1
Metabolizable energy (MJ/kg)	15.54	Chloride	10.0
Crude fibre (g/kg)	0.0	Magnesium	1.2
Neutral-detergent fibre (g/kg)	0.0	Potassium	16.0
Acid-detergent fibre (g/kg)	0.0	Sodium	4.4
Crude fat (g/kg)	9.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.1	Copper	0.1
Crude protein (g/kg)	346.0	Iodine	NA
Amino acids (g/kg)		Iron	0.9
Arginine	12.0	Manganese	0.2
Histidine	8.4	Selenium	NA
Isoleucine	13.5	Zinc	4.0
Leucine	34.0	Vitamins	
Lysine	28.0	β-Carotene (mg/kg)	0.0
Methionine (Met)	8.4	Vitamin A (IU/kg)	220.0
Met + cystine	11.7	Vitamin E (IU/kg)	4.1
Phenylalanine (Phe)	16.0	Vitamins (mg/kg)	
Phe + tyrosine	29.0	Biotin	0.33
Threonine	15.1	Choline	1408
Tryptophan	4.4	Folacin	0.62
Valine	23.0	Niacin	11.0
Available lysine	24.7	Pantothenic acid	33.0
		Pyridoxine	4.0
		Riboflavin	19.8
		Thiamin	3.52
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	40.3

IFN, International Feed Number; NA, no data available.
[a]Cattle skimmed milk dehydrated (or dried skimmed milk) is composed of the residue obtained by drying de-fatted milk by thermal means (CFIA, 2015).

Table 4.30. Molasses (cane) (IFN 4-04-696).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	710.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	2469	Calcium	8.2
Digestible energy (MJ/kg)	10.32	Phosphorus (total)	0.8
Metabolizable energy (kcal/kg)	2343	Phosphorus (available)	NA
Metabolizable energy (MJ/kg)	9.8	Chloride	NA
Crude fibre (g/kg)	0.0	Magnesium	3.5
Neutral-detergent fibre (g/kg)	0.0	Potassium	23.8
Acid-detergent fibre (g/kg)	0.0	Sodium	9.0
Crude fat (g/kg)	0.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.0	Copper	59.6
Crude protein (g/kg)	29.0	Iodine	NA
Amino acids (g/kg)		Iron	175.0
Arginine	NA	Manganese	42.2
Histidine	NA	Selenium	NA
Isoleucine	NA	Zinc	NA
Leucine	NA	Vitamins	
Lysine	NA	β-Carotene (mg/kg)	0.0
Methionine (Met)	NA	Vitamin A (IU/kg)	0.0
Met + cystine	NA	Vitamin E (IU/kg)	4.4
Phenylalanine (Phe)	NA	Vitamins (mg/kg)	
Phe + tyrosine	NA	Biotin	0.7
Threonine	NA	Choline	660.0
Tryptophan	NA	Folacin	0.1
Valine	NA	Niacin	45.0
Available lysine	NA	Pantothenic acid	39.0
		Pyridoxine	7.0
		Riboflavin	2.3
		Thiamin	0.9
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]A by-product of the manufacture of sucrose from sugarcane. It must contain not less than 430 g total sugars, expressed as invert, per kg (AAFCO, 2005).

Table 4.31. Molasses (sugarbeet) (IFN 4-00-669).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	770.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	2320	Calcium	2.0
Digestible energy (MJ/kg)	9.71	Phosphorus (total)	0.3
Metabolizable energy (kcal/kg)	2227	Phosphorus (available)	0.2
Metabolizable energy (MJ/kg)	9.32	Chloride	9.0
Crude fibre (g/kg)	0.0	Magnesium	2.3
Neutral-detergent fibre (g/kg)	0.0	Potassium	47.0
Acid-detergent fibre (g/kg)	0.0	Sodium	10.0
Crude fat (g/kg)	0.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.0	Copper	13.0
Crude protein (g/kg)	60.0	Iodine	NA
Amino acids (g/kg)		Iron	117.0
Arginine	NA	Manganese	10.0
Histidine	NA	Selenium	NA
Isoleucine	0.4	Zinc	40.0
Leucine	NA	Vitamins	
Lysine	0.1	β-Carotene (mg/kg)	0.0
Methionine (Met)	NA	Vitamin A (IU/kg)	0.0
Met + cystine	0.1	Vitamin E (IU/kg)	4.0
Phenylalanine (Phe)	NA	Vitamins (mg/kg)	
Phe + tyrosine	NA	Biotin	0.46
Threonine	0.4	Choline	716.0
Tryptophan	NA	Folacin	NA
Valine	NA	Niacin	41.0
Available lysine	0.1	Pantothenic acid	7.0
		Pyridoxine	NA
		Riboflavin	2.3
		Thiamin	NA
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]A by-product of the manufacture or refining of sucrose from sugarbeets (CFIA, 2015).

Table 4.32. Oats (IFN 4-03-309).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	890.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	2630	Calcium	0.5
Digestible energy (MJ/kg)	11.0	Phosphorus (total)	3.8
Metabolizable energy (kcal/kg)	2525	Phosphorus (available)	1.0
Metabolizable energy (MJ/kg)	10.6	Chloride	1.0
Crude fibre (g/kg)	130.0	Magnesium	1.2
Neutral-detergent fibre (g/kg)	286.0	Potassium	5.1
Acid-detergent fibre (g/kg)	89.0	Sodium	0.04
Crude fat (g/kg)	39.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	26.8	Copper	4.6
Crude protein (g/kg)	104.0	Iodine	0.1
Amino acids (g/kg)		Iron	136.0
Arginine	8.3	Manganese	26.3
Histidine	2.7	Selenium	0.01
Isoleucine	4.5	Zinc	30.5
Leucine	8.4	Vitamins	
Lysine	5.1	β-Carotene (mg/kg)	3.7
Methionine (Met)	2.2	Vitamin A (IU/kg)	987.0
Met + cystine	5.0	Vitamin E (IU/kg)	7.8
Phenylalanine (Phe)	5.8	Vitamins (mg/kg)	
Phe + tyrosine	9.9	Biotin	0.24
Threonine	3.9	Choline	946.0
Tryptophan	1.3	Folacin	0.3
Valine	5.7	Niacin	19.0
Available lysine	2.9	Pantothenic acid	13.0
		Pyridoxine	2.0
		Riboflavin	1.7
		Thiamin	6.0
		Vitamins (µg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The whole seed of the oat plant (CFIA, 2015).

Table 4.33. Oat groats (IFN 4-03-331).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	890.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3690	Calcium	0.7
Digestible energy (MJ/kg)	15.44	Phosphorus (total)	4.5
Metabolizable energy (kcal/kg)	3465	Phosphorus (available)	1.7
Metabolizable energy (MJ/kg)	14.5	Chloride	NA
Crude fibre (g/kg)	26.0	Magnesium	0.9
Neutral-detergent fibre (g/kg)	NA	Potassium	3.4
Acid-detergent fibre (g/kg)	NA	Sodium	0.5
Crude fat (g/kg)	60.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	26.8	Copper	6.4
Crude protein (g/kg)	160.0	Iodine	NA
Amino acids (g/kg)		Iron	35.0
Arginine	9.0	Manganese	28.6
Histidine	2.5	Selenium	NA
Isoleucine	5.0	Zinc	NA
Leucine	10.0	Vitamins	
Lysine	4.5	β-Carotene (mg/kg)	NA
Methionine (Met)	2.0	Vitamin A (IU/kg)	NA
Met + cystine	4.6	Vitamin E (IU/kg)	15.0
Phenylalanine (Phe)	7.0	Vitamins (mg/kg)	
Phe + tyrosine	13.0	Biotin	0.2
Threonine	5.0	Choline	1230
Tryptophan	1.8	Folacin	0.3
Valine	6.5	Niacin	18.0
Available lysine	3.6	Pantothenic acid	11.0
		Pyridoxine	2.0
		Riboflavin	1.3
		Thiamin	6.8
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]Cleaned oats without hulls (CFIA, 2015).

Table 4.34. Peanut (groundnut) meal expeller (IFN 5-03-649).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	930.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3895	Calcium	1.7
Digestible energy (MJ/kg)	16.3	Phosphorus (total)	5.9
Metabolizable energy (kcal/kg)	3560	Phosphorus (available)	0.7
Metabolizable energy (MJ/kg)	14.9	Chloride	0.3
Crude fibre (g/kg)	69.0	Magnesium	3.3
Neutral-detergent fibre (g/kg)	146.0	Potassium	12.0
Acid-detergent fibre (g/kg)	91.0	Sodium	0.6
Crude fat (g/kg)	65.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	17.3	Copper	15.0
Crude protein (g/kg)	432.0	Iodine	0.4
Amino acids (g/kg)		Iron	285.0
Arginine	47.9	Manganese	39.0
Histidine	10.1	Selenium	0.28
Isoleucine	14.1	Zinc	47.0
Leucine	27.7	Vitamins	
Lysine	14.8	β-Carotene (mg/kg)	0.0
Methionine (Met)	5.0	Vitamin A (IU/kg)	0.0
Met + cystine	11.0	Vitamin E (IU/kg)	2.7
Phenylalanine (Phe)	20.2	Vitamins (mg/kg)	
Phe + tyrosine	37.6	Biotin	0.35
Threonine	11.6	Choline	1848
Tryptophan	4.1	Folacin	0.7
Valine	17.0	Niacin	166.0
Available lysine	13.0	Pantothenic acid	47.0
		Pyridoxine	7.4
		Riboflavin	5.2
		Thiamin	7.1
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The ground residual product obtained after extraction of most of the oil from peanut (groundnut) kernels by a mechanical extraction process (CFIA, 2015).

Table 4.35. Peas, field (IFN 5-03-600).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	890.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3435	Calcium	0.5
Digestible energy (MJ/kg)	14.04	Phosphorus (total)	5.0
Metabolizable energy (kcal/kg)	3210	Phosphorus (available)	2.0
Metabolizable energy (MJ/kg)	13.43	Chloride	0.5
Crude fibre (g/kg)	38.3	Magnesium	1.2
Neutral-detergent fibre (g/kg)	110.4	Potassium	10.5
Acid-detergent fibre (g/kg)	45.4	Sodium	0.02
Crude fat (g/kg)	21.4	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	4.7	Copper	8.1
Crude protein (g/kg)	199.4	Iodine	0.26
Amino acids (g/kg)		Iron	65.0
Arginine	16.7	Manganese	4.5
Histidine	5.4	Selenium	0.01
Isoleucine	9.2	Zinc	36.9
Leucine	15.5	Vitamins	
Lysine	15.5	β-Carotene (mg/kg)	1.0
Methionine (Met)	2.8	Vitamin A (IU/kg)	267.0
Met + cystine	6.2	Vitamin E (IU/kg)	0.2
Phenylalanine (Phe)	10.5	Vitamins (mg/kg)	
Phe + tyrosine	18.9	Biotin	0.15
Threonine	8.4	Choline	547.0
Tryptophan	1.9	Folacin	0.2
Valine	10.1	Niacin	31.0
Available lysine	12.2	Pantothenic acid	18.7
		Pyridoxine	1.0
		Riboflavin	1.8
		Thiamin	4.6
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The entire seed from the field pea plant *Pisum sativum* (CFIA, 2015).

Table 4.36. Potatoes, cooked (IFN 4-03-787).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	222.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	956	Calcium	0.14
Digestible energy (MJ/kg)	4.0	Phosphorus (total)	0.7
Metabolizable energy (kcal/kg)	918	Phosphorus (available)	0.6
Metabolizable energy (MJ/kg)	3.84	Chloride	NA
Crude fibre (g/kg)	7.5	Magnesium	0.25
Neutral-detergent fibre (g/kg)	NA	Potassium	5.5
Acid-detergent fibre (g/kg)	26.7	Sodium	0.07
Crude fat (g/kg)	1.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.01	Copper	1.75
Crude protein (g/kg)	24.5	Iodine	0.05
Amino acids (g/kg)		Iron	13.75
Arginine	1.1	Manganese	1.75
Histidine	0.5	Selenium	0.02
Isoleucine	4.1	Zinc	3.75
Leucine	1.4	Vitamins	
Lysine	1.43	β-Carotene (mg/kg)	0.01
Methionine (Met)	0.4	Vitamin A (IU/kg)	2.61
Met + cystine	0.7	Vitamin E (IU/kg)	0.13
Phenylalanine (Phe)	1.0	Vitamins (mg/kg)	
Phe + tyrosine	1.9	Biotin	0.01
Threonine	0.9	Choline	206.0
Tryptophan	0.4	Folacin	0.18
Valine	1.3	Niacin	11.9
Available lysine	1.1	Pantothenic acid	3.33
		Pyridoxine	3.33
		Riboflavin	0.35
		Thiamin	0.9
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The tuberous portion of *Solanum tuberosum*, following heating (not defined by the Association of American Feed Control Officials or the Canadian Food Inspection Agency).

Table 4.37. Potato protein concentrate (IFN 5-25-392).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	910.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	4140	Calcium	1.7
Digestible energy (MJ/kg)	17.32	Phosphorus (total)	2.0
Metabolizable energy (kcal/kg)	3880	Phosphorus (available)	2.0
Metabolizable energy (MJ/kg)	16.23	Chloride	3.0
Crude fibre (g/kg)	5.5	Magnesium	0.25
Neutral-detergent fibre (g/kg)	20.0	Potassium	0.05
Acid-detergent fibre (g/kg)	NA	Sodium	0.05
Crude fat (g/kg)	20.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	NA	Copper	29.0
Crude protein (g/kg)	755.0	Iodine	NA
Amino acids (g/kg)		Iron	NA
Arginine	42.7	Manganese	NA
Histidine	18.2	Selenium	NA
Isoleucine	45.2	Zinc	NA
Leucine	86.4	Vitamins	
Lysine	64.0	β-Carotene (mg/kg)	NA
Methionine (Met)	19.2	Vitamin A (IU/kg)	NA
Met + cystine	32.0	Vitamin E (IU/kg)	NA
Phenylalanine (Phe)	55.2	Vitamins (mg/kg)	
Phe + tyrosine	106.6	Biotin	NA
Threonine	48.0	Choline	NA
Tryptophan	10.6	Folacin	NA
Valine	56.8	Niacin	NA
Available lysine	51.8	Pantothenic acid	NA
		Pyridoxine	NA
		Riboflavin	NA
		Thiamin	NA
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.

[a]Derived from de-starched potato juice from which the proteinaceous fraction has been precipitated by thermal coagulation followed by dehydration (AAFCO, 2005).

Table 4.38. Rice bran (IFN 4-03-928).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	900.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3100	Calcium	0.7
Digestible energy (MJ/kg)	12.97	Phosphorus (total)	13.4
Metabolizable energy (kcal/kg)	2850	Phosphorus (available)	3.1
Metabolizable energy (MJ/kg)	11.92	Chloride	0.7
Crude fibre (g/kg)	130.0	Magnesium	9.0
Neutral-detergent fibre (g/kg)	237.0	Potassium	15.6
Acid-detergent fibre (g/kg)	139.0	Sodium	0.3
Crude fat (g/kg)	130.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	41.2	Copper	9.0
Crude protein (g/kg)	133.0	Iodine	NA
Amino acids (g/kg)		Iron	190.0
Arginine	10.0	Manganese	228.0
Histidine	3.4	Selenium	0.4
Isoleucine	4.4	Zinc	30
Leucine	9.2	Vitamins	
Lysine	5.7	β-Carotene (mg/kg)	0.0
Methionine (Met)	2.6	Vitamin A (IU/kg)	0.0
Met + cystine	5.3	Vitamin E (IU/kg)	9.7
Phenylalanine (Phe)	5.6	Vitamins (mg/kg)	
Phe + tyrosine	9.6	Biotin	0.35
Threonine	4.8	Choline	1135
Tryptophan	1.4	Folacin	220.0
Valine	6.8	Niacin	293.0
Available lysine	4.1	Pantothenic acid	23.0
		Pyridoxine	26.0
		Riboflavin	2.5
		Thiamin	22.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The pericarp or bran layer and germ of the rice, with only such quantity of hull fragments, chipped or broken, brewer's rice and calcium carbonate as is unavoidable in the regular milling of edible rice. It must contain no more than 139 g fibre/kg (AAFCO, 2005).

Table 4.39. Rye (IFN 4-04-047).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	880.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3270	Calcium	3.4
Digestible energy (MJ/kg)	13.68	Phosphorus (total)	7.9
Metabolizable energy (kcal/kg)	3060	Phosphorus (available)	2.8
Metabolizable energy (MJ/kg)	14.3	Chloride	0.3
Crude fibre (g/kg)	21.3	Magnesium	1.2
Neutral-detergent fibre (g/kg)	125.4	Potassium	4.8
Acid-detergent fibre (g/kg)	31.9	Sodium	0.2
Crude fat (g/kg)	16.3	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	7.6	Copper	7.0
Crude protein (g/kg)	82.7	Iodine	0.07
Amino acids (g/kg)		Iron	60.0
Arginine	5.0	Manganese	58.0
Histidine	2.4	Selenium	0.38
Isoleucine	3.7	Zinc	31.0
Leucine	6.4	Vitamins	
Lysine	3.8	β-Carotene (mg/kg)	0.0
Methionine (Met)	1.7	Vitamin A (IU/kg)	0.0
Met + cystine	3.6	Vitamin E (IU/kg)	9.0
Phenylalanine (Phe)	5.0	Vitamins (mg/kg)	
Phe + tyrosine	7.6	Biotin	0.08
Threonine	3.2	Choline	419.0
Tryptophan	1.2	Folacin	0.6
Valine	5.1	Niacin	19.0
Available lysine	2.85	Pantothenic acid	8.0
		Pyridoxine	2.6
		Riboflavin	1.6
		Thiamin	3.6
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The whole grain of the rye plant (CFIA, 2015).

Table 4.40. Sainfoin seed (EU 3.15.1)[a].

Component	Amount	Component	Amount
Dry matter (g/kg)	930.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3750	Calcium	7.1
Digestible energy (MJ/kg)	15.7	Phosphorus (total)	5.1
Metabolizable energy (kcal/kg)	3600	Phosphorus (available)	2.1
Metabolizable energy (MJ/kg)	15.1	Chloride	NA
Crude fibre (g/kg)	177.5	Magnesium	1.7
Neutral-detergent fibre (g/kg)	321.3	Potassium	10.1
Acid-detergent fibre (g/kg)	191.5	Sodium	0.03
Crude fat (g/kg)	64.4	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	NA	Copper	7.7
Crude protein (g/kg)	291.0	Iodine	NA
Amino acids (g/kg)		Iron	97.7
Arginine	31.4	Manganese	25.3
Histidine	11.1	Selenium	0.06
Isoleucine	10.5	Zinc	44.1
Leucine	18.6	Vitamins	
Lysine	15.4	β-Carotene (mg/kg)	NA
Methionine (Met)	5.2	Vitamin A (IU/kg)	NA
Met + cystine	9.0	Vitamin E (IU/kg)	NA
Phenylalanine (Phe)	10.8	Vitamins (mg/kg)	
Phe + tyrosine	20.1	Biotin	NA
Threonine	10.2	Choline	NA
Tryptophan	NA	Folacin	NA
Valine	12.2	Niacin	NA
Available lysine	NA	Pantothenic acid	NA
		Pyridoxine	NA
		Riboflavin	NA
		Thiamin	NA
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

[a]The whole seed of sainfoin, EU feed catalogue (EU 575/2011). NA, no data available.

Table 4.41. Sainfoin seed dehulled (EU 3.15.1)[a].

Component	Amount	Component	Amount
Dry matter (g/kg)	930.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3870	Calcium	7.1
Digestible energy (MJ/kg)	16.2	Phosphorus (total)	5.1
Metabolizable energy (kcal/kg)	3715	Phosphorus (available)	2.1
Metabolizable energy (MJ/kg)	15.5	Chloride	NA
Crude fibre (g/kg)	70.0	Magnesium	1.7
Neutral-detergent fibre (g/kg)	150.0	Potassium	10.1
Acid-detergent fibre (g/kg)	191.5	Sodium	0.03
Crude fat (g/kg)	68.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	NA	Copper	7.7
Crude protein (g/kg)	375.0	Iodine	NA
Amino acids (g/kg)		Iron	97.7
Arginine	31.4	Manganese	25.3
Histidine	11.1	Selenium	0.06
Isoleucine	10.5	Zinc	44.1
Leucine	18.6	Vitamins	
Lysine	18.8	β-Carotene (mg/kg)	NA
Methionine (Met)	5.2	Vitamin A (IU/kg)	NA
Met + cystine	9.0	Vitamin E (IU/kg)	NA
Phenylalanine (Phe)	10.8	Vitamins (mg/kg)	
Phe + tyrosine	20.1	Biotin	NA
Threonine	10.2	Choline	NA
Tryptophan	NA	Folacin	NA
Valine	12.2	Niacin	NA
Available lysine	NA	Pantothenic acid	NA
		Pyridoxine	NA
		Riboflavin	NA
		Thiamin	NA
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

[a]The dehulled whole seed of sainfoin, EU feed catalogue (EU 575/2011). NA, no data available.

Table 4.42. Sesame meal expeller (IFN 5-04-220).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	930.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3350	Calcium	19.0
Digestible energy (MJ/kg)	14.02	Phosphorus (total)	12.2
Metabolizable energy (kcal/kg)	3035	Phosphorus (available)	2.5
Metabolizable energy (MJ/kg)	12.70	Chloride	0.7
Crude fibre (g/kg)	57.0	Magnesium	5.4
Neutral-detergent fibre (g/kg)	180.0	Potassium	11.0
Acid-detergent fibre (g/kg)	132.0	Sodium	0.4
Crude fat (g/kg)	75.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	30.7	Copper	34.0
Crude protein (g/kg)	426.0	Iodine	NA
Amino acids (g/kg)		Iron	93.0
Arginine	48.6	Manganese	53.0
Histidine	9.8	Selenium	0.21
Isoleucine	14.7	Zinc	100.0
Leucine	27.4	Vitamins	
Lysine	10.1	β-Carotene (mg/kg)	0.2
Methionine (Met)	11.5	Vitamin A (IU/kg)	53.4
Met + cystine	19.7	Vitamin E (IU/kg)	1.0
Phenylalanine (Phe)	17.7	Vitamins (mg/kg)	
Phe + tyrosine	32.9	Biotin	0.24
Threonine	14.4	Choline	1536
Tryptophan	5.4	Folacin	0.3
Valine	18.5	Niacin	30.0
Available lysine	8.3	Pantothenic acid	6.0
		Pyridoxine	12.5
		Riboflavin	3.6
		Thiamin	2.8
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The ground residual product obtained after extraction of most of the oil from *Sesamum indicum* seeds by a mechanical extraction process (not defined by the Association of American Feed Control Officials or the Canadian Food Inspection Agency).

Table 4.43. Sorghum (milo) (IFN 4-04-444).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	880.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3380	Calcium	0.3
Digestible energy (MJ/kg)	14.14	Phosphorus (total)	2.9
Metabolizable energy (kcal/kg)	3340	Phosphorus (available)	0.6
Metabolizable energy (MJ/kg)	13.97	Chloride	0.9
Crude fibre (g/kg)	27.0	Magnesium	1.5
Neutral-detergent fibre (g/kg)	180.0	Potassium	3.5
Acid-detergent fibre (g/kg)	83.0	Sodium	0.1
Crude fat (g/kg)	29.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	13.5	Copper	5.0
Crude protein (g/kg)	92.0	Iodine	0.4
Amino acids (g/kg)		Iron	45.0
Arginine	3.8	Manganese	15.0
Histidine	2.3	Selenium	0.2
Isoleucine	3.7	Zinc	15.0
Leucine	12.1	Vitamins	
Lysine	2.2	β-Carotene (mg/kg)	NA
Methionine (Met)	1.7	Vitamin A (IU/kg)	NA
Met + cystine	3.4	Vitamin E (IU/kg)	12.1
Phenylalanine (Phe)	4.9	Vitamins (mg/kg)	
Phe + tyrosine	8.4	Biotin	0.26
Threonine	3.1	Choline	668.0
Tryptophan	1.0	Folacin	0.17
Valine	4.6	Niacin	41.0
Available lysine	2.0	Pantothenic acid	12.4
		Pyridoxine	5.2
		Riboflavin	1.3
		Thiamin	3.0
		Vitamins (µg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The whole seed of the sorghum plant of the variety milo (CFIA, 2015).

Table 4.44. Soybeans cooked (IFN 5-04-597).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	900.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	4140	Calcium	2.5
Digestible energy (MJ/kg)	17.32	Phosphorus (total)	5.9
Metabolizable energy (kcal/kg)	3960	Phosphorus (available)	2.3
Metabolizable energy (MJ/kg)	16.57	Chloride	0.3
Crude fibre (g/kg)	43.0	Magnesium	2.8
Neutral-detergent fibre (g/kg)	139.0	Potassium	17.0
Acid-detergent fibre (g/kg)	80.0	Sodium	0.3
Crude fat (g/kg)	180.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	104.6	Copper	16.0
Crude protein (g/kg)	352.0	Iodine	0.05
Amino acids (g/kg)		Iron	80.0
Arginine	26.0	Manganese	30.0
Histidine	9.6	Selenium	0.11
Isoleucine	16.1	Zinc	39.0
Leucine	27.5	Vitamins	
Lysine	22.2	β-Carotene (mg/kg)	1.0
Methionine (Met)	5.3	Vitamin A (IU/kg)	267.0
Met + cystine	10.8	Vitamin E (IU/kg)	18.1
Phenylalanine (Phe)	18.3	Vitamins (mg/kg)	
Phe + tyrosine	31.5	Biotin	0.24
Threonine	14.1	Choline	2307
Tryptophan	4.8	Folacin	3.6
Valine	16.8	Niacin	22.0
Available lysine	18.4	Pantothenic acid	15.0
		Pyridoxine	10.8
		Riboflavin	2.6
		Thiamin	11.0
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The product resulting from heating whole soybean seeds without removing any of the component parts (CFIA, 2015).

Table 4.45. Soybean meal expeller (IFN 5-04-600).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	900.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3610	Calcium	2.6
Digestible energy (MJ/kg)	15.1	Phosphorus (total)	6.1
Metabolizable energy (kcal/kg)	2972	Phosphorus (available)	2.3
Metabolizable energy (MJ/kg)	12.43	Chloride	0.7
Crude fibre (g/kg)	59.0	Magnesium	2.5
Neutral-detergent fibre (g/kg)	150.0	Potassium	17.9
Acid-detergent fibre (g/kg)	100.0	Sodium	0.3
Crude fat (g/kg)	48.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	27.9	Copper	22.0
Crude protein (g/kg)	429.0	Iodine	0.15
Amino acids (g/kg)		Iron	157.0
Arginine	30.7	Manganese	31.0
Histidine	11.4	Selenium	0.1
Isoleucine	26.3	Zinc	60.0
Leucine	36.2	Vitamins	
Lysine	27.9	β-Carotene (mg/kg)	NA
Methionine (Met)	6.5	Vitamin A (IU/kg)	NA
Met + cystine	12.1	Vitamin E (IU/kg)	7.0
Phenylalanine (Phe)	22.0	Vitamins (mg/kg)	
Phe + tyrosine	37.5	Biotin	0.33
Threonine	17.2	Choline	2623
Tryptophan	6.1	Folacin	6.4
Valine	22.8	Niacin	31.0
Available lysine	24.8	Pantothenic acid	14.3
		Pyridoxine	5.5
		Riboflavin	3.4
		Thiamin	3.9
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The product obtained by grinding the cake or chips which remain after removal of most of the oil from soybeans by a mechanical extraction process (AAFCO, 2005).

Table 4.46. Soybean meal extruded-expelled (IFN 5-04-600).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	945.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	4120	Calcium	NA
Digestible energy (MJ/kg)	17.24	Phosphorus (total)	NA
Metabolizable energy (kcal/kg)	3880	Phosphorus (available)	NA
Metabolizable energy (MJ/kg)	16.23	Chloride	NA
Crude fibre (g/kg)	48.0	Magnesium	NA
Neutral-detergent fibre (g/kg)	NA	Potassium	NA
Acid-detergent fibre (g/kg)	NA	Sodium	NA
Crude fat (g/kg)	48.9	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	NA	Copper	NA
Crude protein (g/kg)	475.2	Iodine	NA
Amino acids (g/kg)		Iron	NA
Arginine	38.5	Manganese	NA
Histidine	12.7	Selenium	NA
Isoleucine	20.8	Zinc	NA
Leucine	36.8	Vitamins	
Lysine	29.6	β-Carotene (mg/kg)	NA
Methionine (Met)	6.5	Vitamin A (IU/kg)	NA
Met + cystine	14.7	Vitamin E (IU/kg)	NA
Phenylalanine (Phe)	24.1	Vitamins (mg/kg)	
Phe + tyrosine	40.1	Biotin	NA
Threonine	18.5	Choline	NA
Tryptophan	7.3	Folacin	NA
Valine	22.4	Niacin	NA
Available lysine	27.0	Pantothenic acid	NA
		Pyridoxine	NA
		Riboflavin	NA
		Thiamin	NA
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	NA

IFN, International Feed Number; NA, no data available.
[a]Soybean meal (with hulls) resulting from a dry extrusion-expeller procedure (extruder temperature 156°C and production rate 850 kg/h).

Table 4.47. Sugarbeet pulp dried (IFN 4-00-669).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	910.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	2865	Calcium	7.0
Digestible energy (MJ/kg)	12.0	Phosphorus (total)	1.0
Metabolizable energy (kcal/kg)	2495	Phosphorus (available)	0.5
Metabolizable energy (MJ/kg)	10.44	Chloride	1.0
Crude fibre (g/kg)	182.0	Magnesium	2.2
Neutral-detergent fibre (g/kg)	424.0	Potassium	6.1
Acid-detergent fibre (g/kg)	243.0	Sodium	2.0
Crude fat (g/kg)	8.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	NA	Copper	11.0
Crude protein (g/kg)	86.0	Iodine	NA
Amino acids (g/kg)		Iron	411.0
Arginine	3.2	Manganese	46.0
Histidine	2.3	Selenium	0.09
Isoleucine	3.1	Zinc	12.0
Leucine	5.3	Vitamins	
Lysine	5.2	β-Carotene (mg/kg)	10.6
Methionine (Met)	0.7	Vitamin A (IU/kg)	2830
Met + cystine	1.3	Vitamin E (IU/kg)	13.2
Phenylalanine (Phe)	3.0	Vitamins (mg/kg)	
Phe + tyrosine	7.0	Biotin	NA
Threonine	3.8	Choline	818.0
Tryptophan	1.0	Folacin	NA
Valine	4.5	Niacin	18.0
Available lysine	NA	Pantothenic acid	1.3
		Pyridoxine	1.9
		Riboflavin	0.7
		Thiamin	0.4
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The dried residue from sugarbeets which has been cleaned and freed from crowns, leaves and sand, and which has been extracted in the process of manufacturing sugar (AAFCO, 2005).

Table 4.48. Sunflower meal dehulled expeller (IFN 5-30-033).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	930.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3113	Calcium	3.9
Digestible energy (MJ/kg)	13.02	Phosphorus (total)	10.6
Metabolizable energy (kcal/kg)	2737	Phosphorus (available)	2.7
Metabolizable energy (MJ/kg)	11.45	Chloride	1.9
Crude fibre (g/kg)	122.0	Magnesium	7.2
Neutral-detergent fibre (g/kg)	263.0	Potassium	10.6
Acid-detergent fibre (g/kg)	174.0	Sodium	2.2
Crude fat (g/kg)	80.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	19.0	Copper	4.0
Crude protein (g/kg)	414.0	Iodine	0.6
Amino acids (g/kg)		Iron	31.0
Arginine	34.5	Manganese	21.0
Histidine	9.0	Selenium	0.6
Isoleucine	17.6	Zinc	50.6
Leucine	24.7	Vitamins	
Lysine	16.1	β-Carotene (mg/kg)	0.3
Methionine (Met)	9.4	Vitamin A (IU/kg)	80.1
Met + cystine	16.3	Vitamin E (IU/kg)	12.0
Phenylalanine (Phe)	18.0	Vitamins (mg/kg)	
Phe + tyrosine	28.0	Biotin	1.4
Threonine	13.7	Choline	2500
Tryptophan	5.0	Folacin	2.3
Valine	20.1	Niacin	200.0
Available lysine	13.0	Pantothenic acid	5.9
		Pyridoxine	12.5
		Riboflavin	3.4
		Thiamin	33.9
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The meal obtained after the removal of most of the oil from sunflower seeds without hulls by a mechanical extraction process (CFIA, 2015).

Table 4.49. Swedes (IFN 4-04-001).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	103.4	Major minerals (g/kg)	
Digestible energy (kcal/kg)	406	Calcium	0.55
Digestible energy (MJ/kg)	1.7	Phosphorus (total)	0.68
Metabolizable energy (kcal/kg)	390	Phosphorus (available)	NA
Metabolizable energy (MJ/kg)	1.63	Chloride	NA
Crude fibre (g/kg)	12.0	Magnesium	0.27
Neutral-detergent fibre (g/kg)	NA	Potassium	3.96
Acid-detergent fibre (g/kg)	NA	Sodium	0.24
Crude fat (g/kg)	NA	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.35	Copper	0.47
Crude protein (g/kg)	12.0	Iodine	NA
Amino acids (g/kg)		Iron	6.1
Arginine	1.74	Manganese	2.0
Histidine	0.35	Selenium	0.1
Isoleucine	0.59	Zinc	3.5
Leucine	0.45	Vitamins	
Lysine	0.46	β-Carotene (mg/kg)	0.01
Methionine (Met)	0.12	Vitamin A (IU/kg)	20.0
Met + cystine	0.27	Vitamin E (IU/kg)	3.0
Phenylalanine (Phe)	0.36	Vitamins (mg/kg)	
Phe + tyrosine	0.64	Biotin	NA
Threonine	0.54	Choline	NA
Tryptophan	0.15	Folacin	0.25
Valine	0.56	Niacin	8.24
Available lysine	NA	Pantothenic acid	1.88
		Pyridoxine	1.18
		Riboflavin	0.47
		Thiamin	1.06
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]Root crop of *Brassica napus* (*Napobrassica* group) (not defined by the Association of American Feed Control Officials or the Canadian Food Inspection Agency).

Table 4.50. Triticale (IFN 4-20-362).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	900.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3210	Calcium	0.9
Digestible energy (MJ/kg)	13.4	Phosphorus (total)	2.6
Metabolizable energy (kcal/kg)	3075	Phosphorus (available)	1.6
Metabolizable energy (MJ/kg)	12.86	Chloride	0.3
Crude fibre (g/kg)	23.8	Magnesium	1.0
Neutral-detergent fibre (g/kg)	109.9	Potassium	4.6
Acid-detergent fibre (g/kg)	39.7	Sodium	0.3
Crude fat (g/kg)	13.4	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	7.1	Copper	2.8
Crude protein (g/kg)	104.4	Iodine	NA
Amino acids (g/kg)		Iron	43.6
Arginine	4.8	Manganese	37.1
Histidine	2.2	Selenium	0.5
Isoleucine	3.3	Zinc	16
Leucine	6.4	Vitamins	
Lysine	3.3	β-Carotene (mg/kg)	NA
Methionine (Met)	1.7	Vitamin A (IU/kg)	NA
Met + cystine	3.8	Vitamin E (IU/kg)	9.0
Phenylalanine (Phe)	4.1	Vitamins (mg/kg)	
Phe + tyrosine	6.8	Biotin	1.0
Threonine	3.0	Choline	462.0
Tryptophan	1.2	Folacin	0.73
Valine	4.3	Niacin	14.3
Available lysine	2.7	Pantothenic acid	13.23
		Pyridoxine	1.38
		Riboflavin	1.34
		Thiamin	4.16
		Vitamins (µg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The entire seed of the triticale plant *Triticale hexaploide* (CFIA, 2015).

Table 4.51. Wheat (IFN 4-050-211).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	880.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3365	Calcium	0.3
Digestible energy (MJ/kg)	14.0	Phosphorus (total)	3.8
Metabolizable energy (kcal/kg)	3210	Phosphorus (available)	0.9
Metabolizable energy (MJ/kg)	13.3	Chloride	0.6
Crude fibre (g/kg)	27.3	Magnesium	1.3
Neutral-detergent fibre (g/kg)	124.2	Potassium	4.2
Acid-detergent fibre (g/kg)	28.2	Sodium	0.02
Crude fat (g/kg)	20.3	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	9.3	Copper	4.1
Crude protein (g/kg)	120.7	Iodine	0.04
Amino acids (g/kg)		Iron	37
Arginine	5.8	Manganese	26.4
Histidine	2.8	Selenium	0.01
Isoleucine	4.1	Zinc	32.1
Leucine	6.5	Vitamins	
Lysine	3.1	β-Carotene (mg/kg)	0.4
Methionine (Met)	2.3	Vitamin A (IU/kg)	106.8
Met + cystine	4.7	Vitamin E (IU/kg)	11.6
Phenylalanine (Phe)	5.2	Vitamins (mg/kg)	
Phe + tyrosine	8.9	Biotin	0.11
Threonine	3.4	Choline	778.0
Tryptophan	1.3	Folacin	0.22
Valine	4.8	Niacin	48.0
Available lysine	2.6	Pantothenic acid	9.9
		Pyridoxine	3.4
		Riboflavin	1.4
		Thiamin	4.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number.
[a]The whole seed of the wheat plant (CFIA, 2015).

Table 4.52. Wheat middlings (Wheatfeed) (IFN 4-05-205).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	890.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3075	Calcium	1.2
Digestible energy (MJ/kg)	12.87	Phosphorus (total)	9.3
Metabolizable energy (kcal/kg)	3025	Phosphorus (available)	3.8
Metabolizable energy (MJ/kg)	12.66	Chloride	0.4
Crude fibre (g/kg)	73.0	Magnesium	4.1
Neutral-detergent fibre (g/kg)	356.0	Potassium	10.6
Acid-detergent fibre (g/kg)	107.0	Sodium	0.5
Crude fat (g/kg)	42.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	17.4	Copper	10.0
Crude protein (g/kg)	159.0	Iodine	NA
Amino acids (g/kg)		Iron	84.0
Arginine	9.7	Manganese	100.0
Histidine	4.4	Selenium	0.72
Isoleucine	5.3	Zinc	92.0
Leucine	10.6	Vitamins	
Lysine	5.7	β-Carotene (mg/kg)	3.0
Methionine (Met)	2.6	Vitamin A (IU/kg)	801.0
Met + cystine	5.8	Vitamin E (IU/kg)	20.1
Phenylalanine (Phe)	7.0	Vitamins (mg/kg)	
Phe + tyrosine	9.9	Biotin	0.33
Threonine	5.1	Choline	1187
Tryptophan	2.0	Folacin	0.76
Valine	7.5	Niacin	72.0
Available lysine	4.7	Pantothenic acid	15.6
		Pyridoxine	9.0
		Riboflavin	1.8
		Thiamin	16.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]Consists of the fine bran particles, germ and a small proportion of floury endosperm particles as separated in the usual processes of commercial flour milling (CFIA, 2015). It has to contain less than 95 g crude fibre per kg.

Table 4.53. Wheat shorts (IFN 4-05-201).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	880.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	2985	Calcium	0.9
Digestible energy (MJ/kg)	12.49	Phosphorus (total)	8.4
Metabolizable energy (kcal/kg)	2920	Phosphorus (available)	3.4
Metabolizable energy (MJ/kg)	12.22	Chloride	0.4
Crude fibre (g/kg)	69.0	Magnesium	2.5
Neutral-detergent fibre (g/kg)	284.0	Potassium	10.6
Acid-detergent fibre (g/kg)	86.0	Sodium	0.2
Crude fat (g/kg)	46.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	19.0	Copper	12.0
Crude protein (g/kg)	160.0	Iodine	NA
Amino acids (g/kg)		Iron	100.0
Arginine	10.7	Manganese	89.0
Histidine	4.3	Selenium	0.75
Isoleucine	5.8	Zinc	100.0
Leucine	10.2	Vitamins	
Lysine	7.0	β-Carotene (mg/kg)	NA
Methionine (Met)	2.5	Vitamin A (IU/kg)	NA
Met + cystine	5.3	Vitamin E (IU/kg)	NA
Phenylalanine (Phe)	7.0	Vitamins (mg/kg)	
Phe + tyrosine	12.1	Biotin	0.24
Threonine	5.7	Choline	1170
Tryptophan	2.2	Folacin	1.4
Valine	8.7	Niacin	107.0
Available lysine	5.0	Pantothenic acid	22.3
		Pyridoxine	7.2
		Riboflavin	3.3
		Thiamin	18.1
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	0.0

IFN, International Feed Number; NA, no data available.
[a]The fine particles of wheat bran, wheat germ, wheat flour, and the offal from the 'tail of the mill'. This product must be obtained in the usual process of commercial milling and must contain no more than 70 g fibre per kg (AAFCO, 2005).

Table 4.54. Whey sweet dehydrated (IFN 4-01-182).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	960.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3335	Calcium	7.5
Digestible energy (MJ/kg)	13.95	Phosphorus (total)	7.2
Metabolizable energy (kcal/kg)	3190	Phosphorus (available)	7.0
Metabolizable energy (MJ/kg)	13.35	Chloride	14.0
Crude fibre (g/kg)	0.0	Magnesium	1.3
Neutral-detergent fibre (g/kg)	0.0	Potassium	19.6
Acid-detergent fibre (g/kg)	0.0	Sodium	9.4
Crude fat (g/kg)	9.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.1	Copper	13.0
Crude protein (g/kg)	121.0	Iodine	NA
Amino acids (g/kg)		Iron	130.0
Arginine	2.6	Manganese	3.0
Histidine	2.3	Selenium	0.12
Isoleucine	6.2	Zinc	10.0
Leucine	10.8	Vitamins	
Lysine	9.0	β-Carotene (mg/kg)	NA
Methionine (Met)	1.7	Vitamin A (IU/kg)	NA
Met + cystine	4.2	Vitamin E (IU/kg)	0.3
Phenylalanine (Phe)	3.6	Vitamins (mg/kg)	
Phe + tyrosine	6.1	Biotin	0.27
Threonine	7.2	Choline	1820
Tryptophan	1.8	Folacin	0.85
Valine	6.0	Niacin	10.0
Available lysine	8.0	Pantothenic acid	47.0
		Pyridoxine	4.0
		Riboflavin	27.1
		Thiamin	4.1
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	23.0

IFN, International Feed Number; NA, no data available.
[a]Cattle whey dehydrated (or dried whey) consists of the residue remaining after the drying or evaporating of whey by thermal means (CFIA, 2015).

Table 4.55. Whey sweet fluid (IFN 4-01-134).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	69.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	241	Calcium	0.47
Digestible energy (MJ/kg)	1.0	Phosphorus (total)	0.46
Metabolizable energy (kcal/kg)	231	Phosphorus (available)	0.45
Metabolizable energy (MJ/kg)	0.97	Chloride	NA
Crude fibre (g/kg)	0	Magnesium	0.08
Neutral-detergent fibre (g/kg)	0	Potassium	1.61
Acid-detergent fibre (g/kg)	0	Sodium	0.54
Crude fat (g/kg)	3.6	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.08	Copper	0.04
Crude protein (g/kg)	15.0	Iodine	NA
Amino acids (g/kg)		Iron	0.6
Arginine	0.23	Manganese	0.01
Histidine	0.18	Selenium	0.02
Isoleucine	0.52	Zinc	1.3
Leucine	0.9	Vitamins	
Lysine	1.1	β-Carotene (mg/kg)	0.0
Methionine (Met)	0.15	Vitamin A (IU/kg)	120.0
Met + cystine	0.5	Vitamin E (IU/kg)	0.0
Phenylalanine (Phe)	0.3	Vitamins (mg/kg)	
Phe + tyrosine	0.54	Biotin	0.04
Threonine	0.8	Choline	127.7
Tryptophan	0.21	Folacin	0.01
Valine	0.46	Niacin	0.74
Available lysine	1.0	Pantothenic acid	3.83
		Pyridoxine	0.31
		Riboflavin	1.58
		Thiamin	0.36
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	2.8

IFN, International Feed Number; NA, no data available.
[a]Cattle whey fresh (or whey or liquid whey) is the product obtained as a fluid by separating the coagulum from milk, cream, skimmed milk or cheese. It has to be labelled with the following statement in English or French: 'This product is free of antimicrobial activity and is not a source of viable microbial cells' (CFIA, 2015).

Table 4.56. White fishmeal (IFN 5-00-025).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	910.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3395	Calcium	70.0
Digestible energy (MJ/kg)	14.2	Phosphorus (total)	35.0
Metabolizable energy (kcal/kg)	2810	Phosphorus (available)	35.0
Metabolizable energy (MJ/kg)	11.76	Chloride	5.0
Crude fibre (g/kg)	0.0	Magnesium	2.2
Neutral-detergent fibre (g/kg)	0.0	Potassium	11.0
Acid-detergent fibre (g/kg)	0.0	Sodium	9.7
Crude fat (g/kg)	48.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.8	Copper	8.0
Crude protein (g/kg)	633.0	Iodine	NA
Amino acids (g/kg)		Iron	80.0
Arginine	42.0	Manganese	10.0
Histidine	19.3	Selenium	1.5
Isoleucine	31.0	Zinc	80.0
Leucine	45.0	Vitamins	
Lysine	43.0	β-Carotene (mg/kg)	0.0
Methionine (Met)	16.5	Vitamin A (IU/kg)	0.0
Met + cystine	24.0	Vitamin E (IU/kg)	5.6
Phenylalanine (Phe)	28.0	Vitamins (mg/kg)	
Phe + tyrosine	45.5	Biotin	0.14
Threonine	26.0	Choline	4050
Tryptophan	7.0	Folacin	0.3
Valine	32.5	Niacin	38.0
Available lysine	38.3	Pantothenic acid	4.7
		Pyridoxine	5.9
		Riboflavin	4.6
		Thiamin	1.5
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	71.0

IFN, International Feed Number; NA, no data available.

[a]Fishmeal is the clean, dried, ground tissue of undecomposed whole fish or fish cuttings, either or both, with or without the extraction of part of the oil (AAFCO, 2005). White fishmeal is a product containing not more than 60 g fat/kg and not more than 40 g salt/kg, obtained from white fish or white fish waste such as filleting offal. For organic feeding the fat should be extracted by mechanical means.

Table 4.57. Yeast brewer's dehydrated (IFN 7-05-527).[a]

Component	Amount	Component	Amount
Dry matter (g/kg)	930.0	Major minerals (g/kg)	
Digestible energy (kcal/kg)	3225	Calcium	1.6
Digestible energy (MJ/kg)	13.49	Phosphorus (total)	14.4
Metabolizable energy (kcal/kg)	3025	Phosphorus (available)	14.0
Metabolizable energy (MJ/kg)	12.66	Chloride	1.2
Crude fibre (g/kg)	29.0	Magnesium	2.3
Neutral-detergent fibre (g/kg)	40.0	Potassium	18.0
Acid-detergent fibre (g/kg)	30.0	Sodium	1.0
Crude fat (g/kg)	17.0	Trace minerals (mg/kg)	
Linoleic acid (g/kg)	0.4	Copper	33.0
Crude protein (g/kg)	459.0	Iodine	NA
Amino acids (g/kg)		Iron	215.0
Arginine	22.0	Manganese	8.0
Histidine	10.9	Selenium	1.0
Isoleucine	21.5	Zinc	49.0
Leucine	31.3	Vitamins	
Lysine	32.2	β-Carotene (mg/kg)	NA
Methionine (Met)	7.4	Vitamin A (IU/kg)	NA
Met + cystine	12.4	Vitamin E (IU/kg)	0.0
Phenylalanine (Phe)	18.3	Vitamins (mg/kg)	
Phe + tyrosine	33.8	Biotin	0.63
Threonine	22.0	Choline	3984
Tryptophan	5.6	Folacin	9.9
Valine	23.9	Niacin	448.0
Available lysine	23.8	Pantothenic acid	109.0
		Pyridoxine	42.8
		Riboflavin	37.0
		Thiamin	91.8
		Vitamins (μg/kg)	
		Cobalamin (vitamin B_{12})	1.0

IFN, International Feed Number; NA, no data available.

Note: values not available in the above table can be assumed to be similar to those in expeller-soybean meal.

[a]The dried, non-fermentative, non-extracted yeast produced from an unmodified strain of the botanical classification *Saccharomyces* resulting as a by-product from the brewing of beer and ale. It has to be labelled with the following statement in English or French: 'This product is not a source of viable Saccharomyces cells' (CFIA, 2015).

Table 4.58. Suggested maximum inclusion rates of feedstuffs in organic pig diets.

	Maximum inclusion rate (g/kg diet)			
Ingredient	Starter	Grower-finisher	Gestation	Lactation
Barley	100	800	900	500
Beet pulp	0	50	500	100
Brewer's dried grains	0	100	100	100
Canola meal	10	150	150	150
Canola, full-fat	50	100	0	0
Cassava	0	400	400	400
Cottonseed meal	0	100	150	0
Faba beans	0	200	200	100
Fishmeal, menhaden	50	25	25	50
Fishmeal, white	50	25	25	50
Flaxseed	0	50	50	50
Grass meal	0	20	50	10
Herring meal	50	25	25	50
Hominy feed	0	700	700	700
Kelp (seaweed) meal	0	25	25	0
Lucerne meal, dehydrated	0	0	50	0
Lucerne meal, sun-cured	0	0	40	0
Lupin seed	0	150	150	100
Maize	600	800	900	800
Maize distiller's grains with solubles, dehydrated	50	150	400	100
Maize gluten feed	50	100	150	50
Molasses	20	40	20	40
Oats	50	150	500	100
Oats groats	100	0	0	0
Peanut meal	50	75	50	150
Peas	75	300	300	200
Potato protein concentrate	50	50	50	50
Rice bran	50	150	250	150
Rye	0	25	25	10
Safflower meal	25	50	50	25
Sesame meal	25	50	50	25
Skimmed milk, spray-dried	50	0	0	0
Sorghum (milo)	400	800	900	800
Soybean meal	150	250	150	200
Soybeans, full-fat, heat-treated	0	200	100	100
Soy protein concentrate	50	50	0	50
Soy protein isolate	50	50	0	50
Sunflower meal	0	200	100	100
Triticale	100	500	400	400
Wheat	150	500	300	400
Wheat bran	0	100	300	100
Wheat middlings	50	400	600	200
Wheat shorts	10	400	600	200
Whey, dried	40	150	50	50
Yeast, brewer's dried	50	100	100	100

Feedstuffs can be highly variable in composition, especially organic feedstuffs which are grown on land fertilized with manures, and therefore the values should only be used as a guide in diet formulation. In addition some of the data quoted are old, particularly the vitamin values, since more recent data are not available. Although old, the vitamin data should be of interest because organic producers wish to maximize the use of natural ingredients. The vitamin A values assume 261 IU vitamin A per 1 mg β-carotene (Wellenreiter *et al.*, 1969).

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5

Diets for Organic Pig Production

In general, the following is suggested as the minimum range of diets necessary for feeding a herd of organic pigs, assuming a farrow-to-finish operation involving all ages of stock:

- Creep-feed
- Starter diet
- Grower diet
- Finisher diet
- Sow gestation diet
- Sow lactation diet
- Boar diet

A key aim of organic farming is environmental sustainability. Consequently organic producers wish to provide most or all of their required inputs, including feed. However this is not possible on small farms, and even larger farms which may produce some of the feedstuffs required may not have the necessary mixing equipment to allow adequate diets to be prepared on-site. Farms with a land base sufficient for the growing of a variety of crops may be able to mix diets on-site or in a cooperative mill.

Creep-feed is generally a complex type of feed, containing several ingredients not likely to be available on farms. Consequently it is recommended that organic creep-feed be purchased from a reliable source.

Small Farms Producing No Feed Ingredients

These farms have to rely on purchased complete feeds. The feeds should be obtained from reputable manufacturers and producers can use the information provided in this book to help them set the dietary specifications with the feed manufacturer. The purchased feed can be manufactured according to specifications set by the feed manufacturer, by the customer or by a consultant. Most feed manufacturers are willing to provide diets tailored to the wishes of customers and may even manufacture diets according to formulas supplied by the customer. The feeds should be ordered regularly and not stored on the farm for extended periods.

One of the advantages of purchasing a complete feed is that the label provides useful information, including a list of ingredients (in some countries a complete formula) and a guaranteed analysis. The European approach is that the feed label for complete pig (and poultry) feeds must contain a declaration of the contents of crude protein, crude fibre, crude oils and fats, lysine, methionine, calcium, sodium and phosphorus, as well as an ingredient list in descending order of magnitude. Usually, an energy and/or protein value is also stated on the feed label.

The following information is required by law on commercial pig feed labels (complete feeds and supplements) in North America:

1. The net weight of the batch.
2. The product name and the brand name under which the commercial feed is distributed.
3. A guaranteed analysis relating to certain nutrients (CP, lysine, crude fat, CF or ADF, calcium, phosphorus, sodium (or salt), selenium and zinc).
4. The common or usual name of each ingredient used in the manufacture of the feed. In some jurisdictions the use of a collective term for a group of ingredients that perform a similar function is permitted, or the regulations may allow a statement that the feedstuffs used are from an approved list. This is a main difference in labelling from that in some European countries, where the exact formula used is provided.
5. The name and principal mailing address of the manufacturer or the person responsible for distributing the feed.
6. Directions for use.

The information on a commercial feed label provides some useful information to the pig producer but its limitations in North America should be recognized. The DE or ME value is not stated and cannot be calculated from the label, except that the CF level provides some indication on whether low-energy ingredients may have been used and the crude fat level provides some information on whether the feed is likely to be low or high in energy. Information on lysine and methionine contents of pig feeds is optional. Producers who purchase complete feeds from a feed manufacturer will avoid the need to mix their own feeds but should adopt the relevant sections of the quality control programme outlined below.

Larger farms with grain available for farm use

Farms with an adequate supply of grains but no protein crops can purchase a supplement which provides all of the nutrients lacking in the grains. It should be purchased with an accompanying mixing guide. In North America the label information provided with the purchased supplement is similar to that provided above for complete feed. Various supplements (sometimes called concentrates) are sold by feed manufacturers. For instance, one for breeding herds may contain about 400 g CP/kg, also minerals and vitamins, and be designed for mixing with ground grain in stated proportions to provide gestation, lactation and boar diets. The diets produced in this way cannot match exactly the nutrient requirements for all classes of breeding stock, but it is a convenient way for the small producer to mix diets using cereal grains as the only home-produced input. Use of supplement is therefore a compromise between convenience and accuracy in formulation.

Alternatively one or more protein feedstuffs and a premix (preferably separate vitamin and trace mineral premixes) can be purchased.

Larger farms with grain and protein feedstuffs available for farm use

The section below explains the principles of feed formulation and manufacture for those organic producers who choose to mix their feeds on-farm.

Steps in Feed Manufacture On-farm

Feed manufacturing (or compounding) is the process of converting ingredients into balanced diets. It is carried out using a grinder to reduce the particle size of the ingredients to the correct grist, a weigher to measure the weight of each ingredient to be added to the mix, and a mixing machine capable of holding the amount of feed to be mixed. A variety of small mixing machines is available for use on-farm, ranging from paddle-type bakers' mixers to mixers that connect to the power take-off shaft on a tractor. This equipment allows the feed ingredients to be processed and mixed in the correct proportions to produce a finished dietary mixture. Sometimes the mixed feed is then pelleted, or it may be fed to the animals as a meal-type (mash) feed.

Feed formulas

Some producers may wish to use formulas devised by others. Unfortunately there is no readily available source of satisfactory feed formulas that can be recommended to organic producers. However, some formulas are available in the published literature from several countries and are shown below, in some cases with details of the production results when the diets were fed to pigs. Some of the formulas provide information on analysed as well as calculated nutrient data, but only the calculated values have been included below since these values are of main interest for formulation purposes.

Denmark

Denmark is a leader in organic production; therefore the diets used there are of interest to other organic producers. Maribo and Claudi-Magnussen (2002) published details of organic diets formulated to investigate the suitability of a new cultivar of lupin (Prima) to help alleviate the protein shortage in Denmark; these researchers at the Danish Meat Research Institute wished to determine how inclusion of this protein source might affect productivity and meat quality. The pigs were produced at a research station, 180 pigs per group. Starting weight was 27.8 kg and slaughter weight was 97.6 kg. Pigs were fed: (i) a conventional diet (360 wheat, 360 barley, 220 soybean meal, g/kg, plus pure AA), diet 1; (ii) an organic diet (organically produced ingredients: 100 wheat, 280 barley, 100 oats, 80 peas, 110 rape cake, 130 soybeans, g/kg), diet 2; or (iii) an organic diet with lupin (450 barley, 150 wheat, 40 soybeans, 50 peas, 90 rape cake, 150 lupin, g/kg), diet 3. All pigs were fed *ad libitum* for the entire period. The pigs in all groups were raised under traditional conditions in order to eliminate all other effects but those of diet. Results are shown in Table 5.1.

The researchers reported that feed analysis showed the content of CP to be 5 and 10 g/kg higher in diets 2 and 3, respectively, than in the control diet (no details were provided). The explanation was that it is possible to adjust the AA content in conventional diets with pure AA but not in organic diets,

Fig. 5.1. Feeds need to be mixed correctly to ensure good growth and reproduction.

Table 5.1. Comparison of a conventional and two organic diets for finishing pigs (from Maribo and Claudi-Magnussen, 2002).

	Conventional	Organic (traditional)	Organic with lupin meal
Diet composition (g/kg, main ingredients only)			
Wheat	360	100	150
Barley	360	280	450
Oats		100	
Soybean meal	220		
Peas		80	50
Soybeans		130	40
Rapeseed cake		110	90
Lupin			150
Pure amino acids	+		
Production results			
Daily weight gain (g)	872[a]	817[b]	850[a]
Feed intake FUp/kg (kg/kg)	2.40[a]	2.25[b]	2.32[c]
Feed conversion FUp/kg (kg/kg)	2.76	2.75	2.74
Lean meat (%)	60.3	59.6	59.8
Fatty acids in backfat (% of total)			
Saturated	37	31	35
Monounsaturated	39	40	42
Polyunsaturated	24	28	23
Iodine number of backfat	84	93	85

FUp, Feed Units pig (a Scandinavian measure of the net energy value of feed for pigs).
No information was provided on micronutrients or the nutrient composition of the diets.
Values in a row with different superscript letters are significantly different at $P < 0.05$.

in which AA content can be adjusted only by increasing the content of CP. All diets had a slightly lower content of EAA than calculated. The differences were at the same level and therefore it was concluded that this did not affect the overall results. Feed intake was higher and daily weight gain lower in the group fed the traditional organic diet (Table 5.1). There were no differences in feed conversion ratio or lean meat percentage between the three groups. The content of saturated fatty acids in the backfat was higher with the conventional diet and lower with the traditional organic diet. The content of MUFA was lower with the conventional diet and higher with the organic diet containing lupin. The content of PUFA was higher with the traditional organic diet and lower with the organic diet containing lupin. The iodine value (degree of unsaturation) was significantly higher with the traditional organic diet, due probably to the higher iodine product in this diet. For reasons unknown, the iodine value of the backfat was very high with all three diets (83–94), the normal being about 70.

These results suggested that organic diets can be formulated to give production similar to that obtained with conventional diets, also that lupins can be used as an alternative protein source. However, they also suggest that a number of factors need to be taken into account in assessing the adequacy of organic diets. The composition of backfat was affected slightly by diet, which had an influence on meat quality, particularly with the traditional organic diet, and this might have influenced the quality of processed pork products. Feeding with all three diets resulted in an unacceptably high content of unsaturated fatty acids in the backfat for Danish standards, the reason for this being unexplained.

Finland

Partanen *et al.* (2006) conducted a study to test the effects of feeding weaned piglets and growing-finishing pigs on diets based mainly on home-grown organic feedstuffs. In a first experiment peas and faba beans were included at dietary levels of 0, 120, or 240 g/kg. The other main ingredients were barley (300 g/kg), oats (150 g/kg), dehulled oats (decreasing level), whey protein concentrate (decreasing level) and fish meal (20 g/kg). It was found that pigs fed diets containing peas grew as well as those fed the control diet, whereas the highest faba bean level resulted in reduced feed intake and growth rate.

A second experiment involved growing/finishing pigs fed from 27–107 kg liveweight on diets in which 0, 33, or 67% of rapeseed cake was replaced with blue lupin seed. The other main ingredients were barley (450–825 g/kg), rapeseed cake (51–176 g/kg), toasted full-fat soybeans (0 or 70 g/kg) and soybean meal (0, 149 or 195 g/kg). The control diet was supplemented with L-lysine HCl at 1.0 or 1.5 g/kg to provide a total lysine content higher than that in the test diets. The dietary lupin seed level had a quadratic effect on the weight gain, the best growth rate being observed at the 33% replacement level. However, dietary lupin seed level did not influence weight gain during the finishing period or total finishing period. Back fat became softer with increasing dietary lupin levels.

In a third experiment, pigs were fed from 11–107 kg liveweight on a control diet containing soybean meal + L-lysine HCl as the protein source or diets containing rapeseed cake + fish meal, whey protein, or soybean cake + whey protein as the protein source. The best growth performance was obtained when whey protein was used as the protein supplement, followed by soybean cake + whey protein and rapeseed cake + fish meal. The pigs fed organic diets required 2–7 days longer to reach slaughter weight than those fed the control diets. Also, the pigs fed organic diets had fatter carcasses but the eating quality of organic pork did not differ from that of pork from pigs fed the control diet. Feed costs were greater and carcass values lower in the organic-fed pigs than in pigs fed the conventional diet since carcass leanness was reduced.

Based on the findings these authors concluded that peas can be used in organic pig starter diets at a level up to 240 g/kg with no negative effects on growth rate or feed consumption, but that faba beans should be limited to less than 120 g/kg feed. Blue lupin seed can be used at a level of 100–120 g/kg diets for finishing pigs, but higher levels in the growing phase can reduce feed intake and growth rate slightly. Lupins also decreased the firmness of the backfat. The variation in the growth rate was greater in pigs fed organic diets than in those fed conventional diets, particularly during the weaner period. The cost of organic diets was 19–44% higher than that of conventional diets, and the decreased carcass leanness resulting from organic diets also lowered carcass values.

These findings were attributed to a sub-optimal content of amino acids in the test diets due to restrictions in the organic regulations on the inclusion of some conventional feedstuffs and pure amino acids in organic diets. These restrictions made it difficult to formulate diets that met the amino acid requirements of weaned pigs and growing/finishing pigs. As a result the authors concluded that sub-optimal dietary amino acid contents in organic pig diets have to be accepted.

Germany

Germany is another leader in organic research. Sundrum *et al*. (2000) published research findings on the use of on-farm diets for organic pig production, the main objective being to find suitable alternatives for pure AA in organic diets following the IFOAM standards. The alternatives investigated were potato protein, faba beans, lupin seed and peas. The diets were evaluated in terms of their effects on both production and carcass quality. The pigs used were crossbred pigs (Pietrain × [Landrace × Large White]) of 31 kg initial weight. They were fed *ad libitum* to 70 kg and then were fed on a restricted scale to 120 kg live weight. The compositions of the four diets used (conventional plus three organic diets) are shown in Table 5.2. Supplementary AA in the conventional diet were derived from a protein

Table 5.2. On-farm diets for organic pig production: diet composition (from Sundrum *et al.*, 2000).

	Conventional	Faba beans plus potato protein	Peas plus lupin meal	Faba beans plus lupin meal
Grower diets				
Ingredient (g/kg dry matter)				
Wheat		50	200	450
Barley	850	620	280	20
Protein concentrate	150			
Peas			250	
Faba beans		200		300
Lupins			220	180
Potato protein		80		
Trace minerals		30	30	30
Sunflower oil		20	20	20
Nutrient content calculated				
Metabolizable energy (kcal/kg)	3106	3106	3106	3106
Crude protein (g/kg)	161	180	192	201
Crude fibre (g/kg)	45	46	63	66
Lysine (g/kg)	10.5	10.5	9.7	9.7
Methionine + cystine (g/kg)	6.2	6.2	5.2	5.3
Threonine (g/kg)	6.0	6.3	7.9	5.1
Tryptophan (g/kg)	1.9	1.9	2.3	1.8
Finisher diets				
Ingredient (g/kg dry matter)				
Wheat		110	240	400
Barley	890	620	380	220
Protein concentrate	110			
Peas			140	
Faba beans		160		140
Lupins			190	190
Potato protein		60		
Trace minerals		30	30	30
Sunflower oil		20	20	20
Nutrient content calculated				
Metabolizable energy (kcal/kg)	3106	3106	3106	3106
Crude protein (g/kg)	148	162	171	178
Crude fibre (g/kg)	46	43	58	60
Lysine (g/kg)	8.8	8.8	7.9	7.9
Methionine + cystine (g/kg)	5.7	5.7	5.1	5.1
Threonine (g/kg)	6.1	5.3	6.3	5.3
Tryptophan (g/kg)	1.7	1.6	1.9	1.7

concentrate (extracted soybean meal, fishmeal, plus pure lysine, methionine and threonine). In the organic diets they were derived from faba beans plus potato protein, peas plus lupins, or faba beans plus lupins. The cultivar of lupin used was not stated. The diets were formulated to contain the highest level of limiting AA possible using home-grown feedstuffs. Chemical analysis of the diets showed that in general the nutrients were close to the calculated values.

Production results from use of the diets are shown in Table 5.3. The conventional diet and the organic diet containing faba beans plus potato protein gave similar production results, with higher daily live-weight gain and feed intake and a shorter period to market weight than the diets containing the other protein sources. The differences in feed intake and daily live-weight gain were limited to the growing period when the pigs were fed *ad libitum*, suggesting an effect of

Table 5.3. On-farm diets for organic pig production: effect on performance and carcass quality (from Sundrum *et al.*, 2000).

	Conventional	Faba beans plus potato protein	Peas plus lupin meal	Faba beans plus lupin meal
Production measure				
Days to 120 kg	103.4	99.8	115.6	116.8
Daily weight gain (g)				
Overall	857	891	770	767
Grower	886	898	689	688
Finisher	840	889	854	860
Daily feed intake (g)				
Grower	2.02	1.97	1.73	1.76
Finisher	2.60	2.58	2.58	2.59
Feed : gain ratio	2.71	2.58	2.78	2.81
Carcass quality				
Slaughter weight (kg)	93.1	92.1	91.2	91.7
Carcass yield (%)	77.9	76.9	76.7	76.5
Lean meat (%)	56.0	55.6	54.3	53.6
Longissimus dorsi area (cm^2)	56.8	54.3	48.8	48.0
Backfat thickness (cm)	2.4	2.4	2.4	2.4
Intramuscular fat (%)	1.20	1.25	2.90	2.95

lupins on voluntary feed intake. However, overall energy consumption was higher in the faba beans plus lupins group than in the conventional or faba beans plus potato protein groups. Backfat thickness was similar in all dietary treatments, but all other carcass quality traits were generally lower with the organic diets. However, feeding the organic diets resulted in an increase in intramuscular fat content, especially in the peas plus lupins and faba beans plus lupins groups where it increased to 2.90% and 2.95%, respectively.

The results of this research show the importance of feedstuffs such as protein concentrate as a substitute for pure AA in organic pig diets. Organic diets formulated without this AA source resulted in a marked decrease in feed consumption and weight gain during the growing period. In addition, these diets had to be formulated to higher total protein contents in an attempt to achieve the desired AA contents. The reduction in feed intake found with the faba bean and lupin diets might have been due to the high inclusion rate of these feedstuffs. Other researchers have noted a similar effect of faba beans on feed intake (Beste *et al.*, 1990). Other research on feeding lupins to finishing pigs indicates that inclusion rates above 200 g/kg cause a reduction in feed intake (Cheeke and Kelly, 1989; Zettl *et al.*, 1995). However, the type of lupin would have a great influence on its suitability for inclusion in pig diets. In the study in question the inclusion rate of lupin meal in the grower diets was 220 g/kg in the peas plus lupin group and 180 g/kg in the faba beans plus lupin group. Cheeke and Kelly (1989) reported that young pigs were more sensitive to the inhibitory effects of lupin seed than older animals that had been exposed to dietary lupin seed throughout the growing period.

The carcass quality results suggest that the organic diets without potato protein concentrate may have contained an inadequate AA profile, and this may also explain the higher concentration of intramuscular fat with these diets. The investigation showed a negative correlation between intramuscular fat content and rate of live-weight gain. Other research has shown a correlation between AA content of the diet and concentration of intramuscular fat. Even the short-term feeding of an AA-deficient diet between 80 and 110 kg was effective in producing a substantial increase in intramuscular fat content, whereas feed intake, growth rate and feed conversion efficiency were not affected adversely (Cisneros *et al.*, 1996). These findings are of potential importance in relation to the eating quality of organic pork.

One surprising aspect of the study reported by Sundrum *et al.* (2000) was that the diets were apparently not supplemented with vitamins, salt or major minerals and, in spite of the animals being housed indoors without access to sunlight, no signs of vitamin or mineral deficiency were reported with any of the diets. Correspondence with the senior author (A. Sundrum, personal communication, 2006) has indicated that the diets were in fact supplemented with vitamins and major minerals, these details having been omitted from the published report. Producers need to be aware of this correction and ensure that the diets are fortified adequately with vitamins and minerals, if deciding to adopt any of the formulas described in the report by Sundrum *et al.* (2000).

Sweden

Research was carried out at the Swedish University of Agricultural Sciences to compare conventional and organic diets (Lindén *et al.*, 2001). The specific aspect of the study was to determine the effects of organic rearing on kidney levels of cadmium, a toxic trace mineral. Growing pigs ([Swedish Landrace × Swedish Yorkshire] × Hampshire) were used, over the growth period 28 to 107 kg live weight. The conventional pigs were raised indoors and the organic pigs were raised outdoors with access to soil.

In contrast to the feed formulas used by Sundrum *et al.* (2000), the organic diet used in the Swedish study was quite complex. An unexpected ingredient was meat meal, in view of the organic standards prevailing in Europe and the fact that the main ingredients in this diet were certified by KRAV (the Certification Organization for Organic Agriculture in Sweden). Also, the organic diet contained a higher level of vitamin/mineral fortification than the conventional diet. No details were provided on the nutrient contents of the two diets.

The organic diet gave good production, which was slightly better than with the conventional diet. However, the carcasses were fatter. A surprising finding was that cadmium was higher in the tissues of organic pigs than in conventional animals, although the level of this element was higher in the conventional diet. This result suggested that the bioavailability of cadmium may have been higher in the organic diet. Another possible explanation was intake of cadmium from soil. Other research has shown that the intake of soil by pigs may be about 8–12% of dietary DM intake (Fries *et al.*, 1982). However, based on calculations of cadmium intake from soil and feed the researchers calculated that the cadmium intake of the organic pigs would have been similar to that of the conventional pigs. Therefore other factors appeared to be involved in causing the higher kidney cadmium levels in the organic pigs. There was no significant difference in liver cadmium levels between organic and conventional pigs.

UK

The United Kingdom has an active program of research on novel organic diets and feeding systems for pigs. An example is the work of Clements *et al.* (2015) who studied the growth of Gloucester Old Spot weaner gilts and entire boars fed *ad libitum* on diets based on 55% lucerne silage, 30% rolled barley and 1% mineral mix, and a supplement of 14% soybean meal, faba beans or field peas. No significant difference in daily live weight gain was observed during the grower phase (11–14 weeks) between the diet groups, but during the finisher phase (15–22 weeks), the pigs fed the soy and pea diets had significantly faster growth rates than pigs fed the faba bean diet. Although the animals were of a slow-growing breed they grew more slowly than would be expected in pigs fed a diet based on more conventional ingredients, due probably to the relatively low level of energy and nutrients in the silage-based diets. A control group fed more conventionally would have provided an interesting comparison in this study and would have helped to separate the relative effects of breed and diet on growth rate. This silage-based system would have application in the feeding of breeding herds. Overall the findings indicate that successful organic feed systems can be developed using home-grown feed ingredients.

USA

The University of Minnesota has a strong programme in organic agriculture and recommendations on appropriate feed formulas have been issued by their extension service (Shurson, 2012). Examples of feed formulas suggested by this group are shown in Tables 5.4– 5.9.

All feedstuffs in these formulations met organic standards. Interesting aspects of these formulas are that they assume no intake of nutrients from pasture and different summer and winter (assuming an environmental temperature of 0°C) formulas are suggested. The seasonal difference in the formulas is based on the premise that feed

Table 5.4. Suggested organic starter formulas for pigs up to 35 kg (from Shurson, 2012).

	Summer		Winter	
Ingredient (g/kg)				
Maize	544		686.5	
Wheat		534.5		678
Soybeans, full-fat	424	335	280	190
Canola meal		100		100
Dicalcium phosphate	14	11	15	12
Ground limestone	8.0	9.5	8.5	10.0
Salt (NaCl)	5	5	5	5
Vitamin/mineral premix	5	5	5	5
Nutrient analysis (calculated)				
Metabolizable energy (kcal/kg)	3417	3381	3373	3313
Crude protein (g/kg)	194	215	156	184
Lysine (g/kg)	10.8	10.7	8.0	8.0
Calcium (g/kg)	7.3	7.5	7.4	7.6
Phosphorus (g/kg)	6.6	6.6	6.3	6.4

Table 5.5. Suggested organic grower formulas for pigs from 35 to 60 kg (from Shurson, 2012).

	Summer			Winter		
Ingredient (g/kg)						
Barley			636			718
Maize	650			749		
Wheat		611.5			721	
Soybeans, full-fat	319	210		219	100	
Soybean meal			133			50
Canola meal		150			150	
Peas, field			200			200
Dicalcium phosphate	12.5	9.0	12.5	13.5	9.5	13.5
Ground limestone	8.5	9.5	8.5	8.5	9.5	8.5
Salt (NaCl)	5	5	5	5	5	5
Vitamin/mineral premix	5	5	5	5	5	5
Nutrient analysis (calculated)						
Metabolizable energy (kcal/kg)	3392	3377	2980	3362	3328	2914
Crude protein (g/kg)	166	193	178	139	169	145
Lysine (g/kg)	8.8	8.8	9.4	6.8	6.8	7.4
Calcium (g/kg)	7.0	7.0	6.9	7.0	6.9	7.0
Phosphorus (g/kg)	6.0	6.1	6.1	6.0	5.9	6.2

intake is higher in winter than in summer and that the dietary concentration of CP and AA can be reduced in winter so that the total intake of these nutrients is similar with both winter and summer formulations. The authors suggest that the formula specifications be adjusted for genotype differences in the stock being fed, and for variability in the nutrient composition of ingredients.

The formulas in Table 5.8 assume a feeding level of 2 kg per sow per day in summer and 3.4 kg per day in winter; an initial sow weight of 160 kg; a gestation weight gain of 18 kg; and an expected litter size of ten pigs. Organic diets for lactating sows are given in Table 5.9. The lactation formulas are suggested for summer use only, with no winter farrowing unless the animals are housed indoors.

Table 5.6. Suggested organic finisher formulas for pigs from 60 to 85 kg (from Shurson, 2012).

	Summer			Winter		
Ingredient (g/kg)						
Barley			698.5			773
Maize	723			807		
Wheat		690.5			790	
Soybeans, full-fat	250	135		165	35	
Soybean meal			50			
Canola meal		150			150	
Peas, field			225			200
Dicalcium phosphate	7.5	4.5	7.5	9.5	5.5	7.5
Ground limestone	9.5	10.0	9.0	8.5	9.5	9.5
Salt (NaCl)	5	5	5	5	5	5
Vitamin/mineral premix	5	5	5	5	5	5
Nutrient analysis (calculated)						
Metabolizable energy (kcal/kg)	3388	3357	2932	3362	3313	2886
Crude protein (g/kg)	148	177	149	125	156	127
Lysine (g/kg)	7.4	7.4	7.4	5.8	5.6	5.8
Calcium (g/kg)	6.1	6.1	5.9	6.0	5.9	5.9
Phosphorus (g/kg)	4.9	5.1	5.1	5.0	5.0	5.0

Table 5.7. Suggested organic finisher formulas for pigs from 85 to115 kg (from Shurson, 2012).

	Summer			Winter		
Ingredient (g/kg)						
Barley		266.5	725			812.5
Maize	592			591.5		
Wheat		560			688	
Oats	200			258	200	
Soybeans, full-fat	183	150		125	87.5	
Peas, field			250			162.5
Dicalcium phosphate	5.5	3.5	5.5	6.5	4.5	5.5
Ground limestone	9.5	10.0	9.5	9.0	10.0	9.5
Salt (NaCl)	5	5	5	5	5	5
Vitamin/mineral premix	5	5	5	5	5	5
Nutrient analysis (calculated)						
Metabolizable energy (kcal/kg)	3234	3142	2906	3176	3093	2880
Crude protein (g/kg)	137	160	133	123	151	122
Lysine (g/kg)	6.4	6.4	6.4	5.3	5.4	5.4
Calcium (g/kg)	5.6	5.4	5.5	5.5	5.5	5.5
Phosphorus (g/kg)	4.4	4.5	4.6	4.4	4.4	4.6

Table 5.8. Suggested organic sow gestation diets (from Shurson, 2012).

	Summer			Winter	
Ingredient (g/kg)					
Barley			350		400
Maize	552.5			716	
Wheat		614	408		522
Oats	250			205	
Lucerne meal		100			
Soybeans, full-fat	155		50	50	50
Canola meal		150			
Sunflower meal		100			
Peas, field			150		
Dicalcium phosphate	25.0	21.0	23.5	11.5	9.0
Ground limestone	7.5	5.0	8.5	7.5	9.0
Salt (NaCl)	5	5	5	5	5
Vitamin/mineral premix	5	5	5	5	5
Nutrient analysis (calculated)					
Metabolizable energy (kcal/kg)	3130	3180	3000	3181	3038
Crude protein (g/kg)	129	156	146	101	133
Lysine (g/kg)	5.9	5.7	6.2	3.8	4.5
Calcium (g/kg)	9.1	9.2	9.1	5.9	6.0
Phosphorus (g/kg)	7.9	7.9	8.0	5.1	5.3

Table 5.9. Suggested organic sow lactation diets (from Shurson, 2012).

	Summer	
Ingredient (g/kg)		
Barley		570.5
Maize	713	
Soybeans, full-fat		290
Soybean meal	245	
Sunflower meal		
Peas, field		100
Dicalcium phosphate	24.5	20.5
Ground limestone	7.5	9.0
Salt (NaCl)	5	5
Vitamin/mineral premix	5	5
Nutrient analysis (calculated)		
Metabolizable energy (kcal/kg)	3330	3045
Crude protein (g/kg)	179	185
Lysine (g/kg)	9.4	10.0
Calcium (g/kg)	9.1	9.1
Phosphorus (g/kg)	8.1	7.9

Feed Formulation

The following information is required for the formulation of diets when the formula is not fixed and needs to be derived based on the available ingredients.

1. Target values for energy and nutrients in the formula, based on standards for the class of pig in question.
2. Data on the nutrient composition of the ingredients available, in terms of nutrient bioavailability where possible.
3. Constraints on inclusion levels of certain ingredients, based on non-nutritive characteristics such as palatability and pelleting properties.
4. Costs of available ingredients (unless the cost of the diet is unimportant).

The first step in preparing a dietary mixture is to list the available ingredients and their composition. The next step is to formulate an appropriate mixture of ingredients to obtain the target values in the mixture for nutrients required by the class of pig in question. The third step is to prepare the ingredients in a form and in (preferably weighed) amounts suitable for mixing together. The final step is manufacture of the dietary mixture.

The brief outline above assumes that a dry mixture will be prepared. Liquid feeds are handled differently.

Selection of ingredients

The first step in manufacturing high-quality feed is to use high-quality ingredients. Grain should be free of caking, moulds, insects, stones, etc. and should contain a low proportion of broken kernels, which are more likely to encourage mould growth than intact kernels. Grains should contain no more than about 120–140 g moisture/kg for safe storage. Rodent damage and mould contamination are two major problems associated with stored grain. Rodents will eat grain and contaminate it with their droppings which will reduce the palatability of grains and feed, reduce intake of feed and possibly contaminate it with salmonella. Mould growth is enhanced when grain is stored at a high moisture content. Certain moulds produce toxins called mycotoxins which depress pig performance.

A main factor influencing selection of ingredients is availability. Another factor affecting choice of ingredients is quality. This latter feature should be addressed using a quality control programme. Since a detailed chemical analysis of each batch of ingredients is not possible, assumed values for nutrient content (such as those in the tables shown in Chapter 4) are often used. Where possible it is advisable to make allowances in formulations for possible variations in ingredient composition.

Nutrient concentrations in feed ingredients can vary substantially from average values published in nutrient composition tables. The most accurate formulations result when laboratory analysis of ingredients is available. Surveys show that feed quality problems are common. Often the CP, calcium and phosphorus levels in on-farm mixed pig feeds vary considerably from the intended values.

Near infrared reflectance spectroscopy (NIRS) is becoming increasingly used for the analysis of nutrients in feedstuffs. It is very rapid and cost-effective and may eventually replace the slower chemical methods of analysis used currently in the feed manufacturing industry. NIRS may also be used for AA analysis. Another method now being adopted widely in feed manufacture is to use prediction equations based on chemical or NIRS analysis to predict AA contents of some feedstuffs. The NRC (1998) published equations for the prediction of lysine, tryptophan, threonine, methionine and methionine plus cystine in a range of feedstuffs, based on DM and CP content.

Where possible, separate vitamin and trace mineral premixes should be used. Vitamins in contact with minerals over a prolonged period of time in a hot and humid environment lose potency, possibly resulting in vitamin deficiencies and reduced performance. In countries with high ambient temperatures it may be necessary to provide cooled storage facilities. When vitamins and minerals are combined in a single premix, it should be used within 30 days of purchase. Vitamin and trace mineral premixes should be stored in the dark in dry sealed containers. Stabilizing agents are helpful in maintaining premix quality, but must meet organic standards.

Suggested premixes for use in organic diets are shown in Tables 5.10–5.15, based on the 1998 NRC requirements. Separate premixes for breeding and growing animals are appropriate, since their requirements are different. The premixes supply all of the required vitamins and trace minerals and assume no contribution from the main dietary ingredients and forage since these vary and may be low in potency or bioavailability. Producers who wish to include a lower level of premix on the basis that some vitamins and minerals are proved by the main ingredients and forage should do so with care, observing the animals closely for signs of deficiencies and ensuring that the welfare of the animals is not compromised. Vitamin D can be omitted from summer formulations provided the animals have access to sunshine. Vitamin D is recommended in formulations for use in regions north of latitude 42.2°N at all other times of the year. The carrier used in the premixes can be a material such as ground oat hulls.

Premixes meeting these specifications can be obtained from feed manufacturers. Some producers prefer to use macro-premixes instead of premixes of the type suggested. These contain calcium, phosphorus and salt

Table 5.10. Estimated vitamin and trace mineral requirements of breeding pigs, amount per kg diet (90% moisture basis) (from NRC, 1998).

	Bred gilts, sows	Lactating gilts, sows	Boars
Trace minerals (mg/kg)			
Copper	5.0	5.0	5.0
Iodine	0.14	0.14	0.14
Iron	80.0	80.0	80.0
Manganese	20.0	20.0	20.0
Selenium	0.15	0.15	0.15
Zinc	50.0	50.0	50.0
Vitamins (IU/kg)			
Vitamin A	4000	2000	4000
Vitamin D	200	200	200
Vitamin E	44	44	44
Vitamins (mg/kg)			
Biotin	0.2	0.2	0.2
Choline	1250	1250	1250
Folacin	1.3	1.3	1.3
Niacin	10	10	10
Pantothenic acid	12	12	12
Pyridoxine	1.0	1.0	1.0
Riboflavin	3.75	3.75	3.75
Thiamin	1.0	1.0	1.0
Vitamins (μg/kg)			
Cobalamin (vitamin B_{12})	15.0	15.0	15.0

Table 5.11. Composition of a trace mineral premix to provide the NRC (1998) estimated trace mineral requirements in breeder diets when included at 5 kg/t.

Trace mineral	Amount per kg premix	Supplies per kg diet
Copper	1 g	5.0 mg
Iron	16 g	80 mg
Manganese	4 g	20 mg
Selenium	30 mg	0.15 mg
Zinc	10 g	50 mg
Carrier	To 1 kg	

Iodine is usually provided in the form of iodized salt.

in addition to trace minerals, and are supplied with mixing formulas. Their inclusion rate in diets is determined largely by the varying need for supplementary calcium and phosphorus. Organic producers have much more control of the dietary formulation when the premix and major minerals

Table 5.12. Composition of a vitamin premix to provide the NRC (1998) estimated vitamin requirements in breeder diets when included at 5 kg/t.

Vitamin	Amount per kg premix	Supplies per kg diet
Vitamin A	800,000 IU	4,000 IU
Vitamin D	40,000 IU	200 IU
Vitamin E	8,800 IU	44 IU
Biotin	40 mg	0.2 mg
Choline	250 g	1250 mg
Folacin	260 mg	1.3 mg
Niacin	2 g	10 mg
Pantothenic acid	2.4 g	12 mg
Riboflavin	750 mg	3.75 mg
Cobalamin (vitamin B_{12})	3 mg	15.0 μg
Carrier	To 1 kg	

Vitamin D can be omitted from the summer formula for animals with access to direct sunshine.

Table 5.13. Estimated vitamin and trace mineral requirements of growing pigs, amount per kg diet (90% moisture basis) (from NRC, 1998).

	Weight		
	10–20 kg	20–50 kg	50–100 kg
Trace minerals (mg/kg)			
Copper	5.0	4.0	3.5
Iodine	0.14	0.14	0.14
Iron	80	60	50
Manganese	3	2	2
Selenium	0.25	0.15	0.15
Zinc	80	60	50
Vitamins (IU/kg)			
Vitamin A	1750	1300	1300
Vitamin D	200	150	150
Vitamin E	11	11	11
Vitamins (mg/kg)			
Biotin	0.05	0.05	0.05
Choline	400	300	300
Folacin	0.3	0.3	0.3
Niacin	12.5	10	7
Pantothenic acid	9	8	7
Pyridoxine	1.5	1	1
Riboflavin	3	2.5	2
Thiamin	1	1	1
Vitamins (μg/kg)			
Cobalamin (vitamin B_{12})	5	10	5

Table 5.14. Composition of a trace mineral premix to provide the NRC (1998) estimated trace mineral requirements in grower-finisher diets when included at 5 kg/t.

Trace mineral	Amount per kg premix	Supplies per kg diet
Copper	0.8 g	4.0 mg
Iron	12 g	60 mg
Manganese	0.4 g	2 mg
Selenium	30 mg	0.15 mg
Zinc	12 g	60.0 mg
Carrier	To 1 kg	

Iodine is usually provided in the form of iodized salt.

Table 5.15. Composition of a vitamin premix to provide the NRC (1998) estimated vitamin requirements in grower-finisher diets when included at 5 kg/t.

Vitamin	Amount per kg premix	Supplies per kg diet
Vitamin A	260,000 IU	1,300 IU
Vitamin D	30,000 IU	150 IU
Vitamin E	2,200 IU	11 IU
Biotin	10 mg	0.05 mg
Choline	60 g	300 mg
Folacin	60 mg	0.3 mg
Niacin	2 g	10 mg
Pantothenic acid	1.6 g	8 mg
Riboflavin	0.5 g	2.5 mg
Cobalamin (vitamin B_{12})	2 mg	10.0 μg
Carrier	To 1 kg	

Vitamin D can be omitted from the summer formula for animals with access to direct sunshine.

are included in the diet separately. However, producers wishing the convenience of a combined mineral and trace mineral premix should adopt the option of using macro-premixes and follow the mixing directions provided by the supplier to mix appropriate diets.

Formulation involves deciding on the feed-appropriate mixing formula (recipe). As outlined above, some producers use fixed formulas such as those suggested in this book. Others, who have access to a range of feed ingredients, have to change the mixing formula as the ingredients change, e.g. barley being available in place of maize. Producers who use commercial supplements and premixes should have mixing instructions available on the feed tag. Mixing instructions should be followed precisely.

Standards for dietary formulation

Standards for organic pig production can be derived from the NRC (1998) estimates of nutritional requirements outlined in Chapter 3. Some nutritionists have derived recommended standards which are close to the NRC requirements or higher, as exemplified in the suggested Minnesota formulas described above. However, the requirement values estimated by NRC are designed for modern, fast-growing pigs with a high potential for lean-meat development and low carcass fat content. The animals used in organic production are mainly of slow-growing types, which are fatter and contain less lean meat than improved breeds (Wood *et al.*, 1979). Therefore it is logical to modify the NRC values by lowering the DE value to a level that is less likely to promote excessive fatness in these slower-growing animals. Reducing the energy content of the diet also minimizes the need for restricted feeding. In reducing the energy value of the diet it is logical to reduce the CP and AA contents by a similar proportion so that the same ratios of energy to protein and AA are maintained. However, it is recommended that the NRC (1998)-derived values for mineral and vitamin requirements be adopted without modification, to help ensure correct skeletal development and avoid foot and leg problems. Conventional diets are usually formulated with higher levels of minerals and vitamins but this approach is not suggested for organic diets, to minimize nutrient levels above those required for normal growth and reproduction.

Standards based on this approach, and examples of derived feed formulas, are shown in Tables 5.16–5.22. Producers using modern hybrids instead of traditional or heritage genotypes are advised instead to use the NRC (1998) requirement values or the values suggested by the breeding company as the basis for dietary standards.

The diets have been formulated using the available data on the analysed composition

Table 5.16. Suggested standards for energy and major nutrients in diets for organic breeding pigs of heritage type, based on modified NRC (1998) nutrient requirement values (amount per kg diet, 90% moisture basis).

	Bred gilts, sows		Lactating gilts, sows		Boars	
	NRC	Suggested	NRC	Suggested	NRC	Suggested
Digestible energy (kcal/kg)	3400	3000	3400	3300	3400	3100
Digestible energy (MJ/kg)	14.23	12.55	14.23	13.8	14.23	12.55
Metabolizable energy (kcal/kg)	3265	2880	3265	3170	3265	2880
Metabolizable energy (MJ/kg)	13.66	12.05	13.66	13.26	13.66	12.05
Crude protein (g/kg)	128	120	185	180	130	120
Amino acids (g/kg)						
Lysine	5.7	5.5	9.7	9.4	6.0	5.5
Methionine + Cystine	3.8	2.4	4.7	4.5	4.2	3.6
Minerals (g/kg)						
Calcium	7.5	7.5	7.5	7.5	7.5	7.5
Phosphorus (available)	3.5	3.5	3.5	3.5	3.5	3.5
Sodium	1.5	1.5	2.0	2.0	1.5	1.5

Table 5.17. Suggested standards for energy and major nutrients in diets for organic growing/finishing pigs of heritage type, based on modified NRC (1998) nutrient requirement values (amount per kg diet, 90% moisture basis).

	Live weight					
	10–20 kg (Starter)		20–50 kg (Grower)		50–100 kg (Finisher)	
	NRC	Suggested	NRC	Suggested	NRC	Suggested
Digestible energy (kcal/kg)	3400	3300	3400	3100	3400	3100
Digestible energy (MJ/kg)	14.25	13.81	14.25	13.0	14.25	13.0
Metabolizable energy (kcal/kg)	3265	3170	3265	2975	3265	2975
Metabolizable energy (MJ/kg)	13.65	13.25	13.66	12.5	13.66	12.5
Crude protein (g/kg)	209	195	180	164	138	130
Amino acids (g/kg)						
Lysine	11.5	10.9	9.5	8.6	6.6	6.0
Methionine + Cystine	6.5	6.0	5.4	4.9	4.0	3.6
Minerals (g/kg)						
Calcium	7.0	7.0	6.0	6.0	5.0	5.0
Phosphorus (available)	3.2	3.2	2.3	2.3	1.9	1.9
Sodium	1.5	1.5	1.0	1.0	1.0	1.0

of organic feedstuffs and with the aims of maximizing the use of home-grown feedstuffs and minimizing the need for supplementation with pure amino acids. In some cases this results in an excess of crude protein in the diet, which could be reduced with the inclusion of pure forms of lysine and methionine.

Supplementation of the diets with approved sources of enzymes (such as phytase) will help to ensure the maximum utilization of the nutrients contained in the feed ingredients.

The aim of formulation is to match the nutrient values in the mixed feed to the needs of the class of pig in question. Computers are increasingly being used for this purpose, using commercial software based on linear programming and involving a complex set of mathematical equations. To attempt to do the same on a desk calculator is very tedious and time-consuming. The computer is

Table 5.18. Example feed mixtures that meet the suggested dietary specifications for heritage-type dry sows, gilts and boars.

	Example 1	Example 2	Example 3	Example 4
Ingredient, kg				
Barley	415	340	200	400
Wheat		150	200	
Wheatfeed	200	124	265	265
Oats	100	100		50
Canola meal		150		50
Peas, field	249	100	150	150
Faba beans			100	
Sainfoin seed dehulled			50	
Ground limestone	11	11	13	11
Dicalcium phosphate	11	10	8	10
Salt (NaCl)	4	4	4	4
Vitamin Premix	5	5	5	5
Trace mineral Premix	5	5	5	5
Total, kg	1000	1000	1000	1000
Nutrient analysis (calculated)[a]				
Digestible energy (kcal/kg)	3020	3065	3150	3066
Digestible energy (MJ/kg)	12.64	12.86	13.16	12.81
Metabolizable energy (kcal/kg)	2899	2942	3024	2944
Metabolizable energy (MJ/kg)	12.14	12.36	12.66	12.31
Crude protein (g/kg)	139	155	165	156
Lysine	7.1	7.4	7.6	7.4
Methionine + Cystine	4.9	6.1	5.2	5.5
Calcium	7.5	8.4	7.7	7.6
Phosphorus (available)	3.6	3.8	3.6	3.8
Sodium	1.7	1.7	1.7	1.7

[a]Cannot be guaranteed because of ingredient variability.

programmed using NRC or other target nutrient values, tables of feed composition and current prices of ingredients. The mathematical solution obtained lists the amounts of selected ingredients that best meets the specifications set. These specifications may include constraints on upper and lower limits of nutrients allowed in the mixture, and on inclusion levels of certain ingredients. The obtained formula may, but not always, be least-cost. In view of the complexity of the calculations the producer should obtain advice from an experienced nutritionist, at least initially.

A simple computerized system of on-farm formulation is available via the CABI Open Resources page (www.cabi.org/openresources/47906). It is based on a Microsoft Excel-type matrix, using the feedstuff compositional data outlined in Chapter 4 and the suggested standards for energy and nutrients to be provided in organic pig diets that are outlined in this chapter.

It is suggested that producers should select formulas that contain grain by-products as well as those based mainly on whole grains. This approach is in keeping with organic philosophy as it minimizes competition between animals and humans for available food resources. Also, grain by-products are generally richer sources of micronutrients than the whole grains.

Preparation, weighing, batching and blending

Having obtained a suitable formula for the feed in question, the next step is preparing to mix the feed. The procedures involved in

Table 5.19. Example feed mixtures that meet the suggested dietary specifications for heritage-type lactating sows.

	Example 1	Example 2	Example 3	Example 4
Ingredient, kg				
Wheat	400	407	238	400
Maize	100		200	
Wheatfeed	89	75	75	63
Soybean meal	125		200	50
Canola meal		100		50
Peas, field	200	200	150	200
Faba beans	50	80	100	
Sainfoin seed dehulled		100		100
Ground limestone	12	12	12	12
Dicalcium phosphate	9	10	9	9
Salt (NaCl)	5	6	5	6
Vitamin Premix	5	5	5	5
Trace mineral Premix	5	5	5	5
Total, kg	1000	1000	1000	1000
Nutrient analysis (calculated)[a]				
Digestible energy (kcal/kg)	3302	3300	3330	3310
Digestible energy (MJ/kg)	13.81	13.8	13.93	13.85
Metabolizable energy (kcal/kg)	3168	3168	3194	3178
Metabolizable energy (MJ/kg)	13.26	13.3	13.36	13.30
Crude protein (g/kg)	183	195	203	203
Lysine	9.4	9.4	11.3	10.3
Methionine + Cystine	5.8	6.3	6.2	6.2
Calcium	7.6	7.9	7.9	7.9
Phosphorus (available)	3.6	3.5	3.8	3.7
Sodium	2.0	2.4	2.1	2.4+

[a]Cannot be guaranteed because of ingredient variability.

the production of quality feeds are important and should be carried out by trained personnel. Mixing errors are quite common.

Cereal grains and possibly protein sources need to be processed before being added into the mix. To achieve optimal pig performance, it is necessary to process cereal grains through a hammer mill or roller mill to reduce particle size. Reduction of particle size breaks the hard kernel and increases the surface area of the grain in the digestive tract. This improves the efficiency of digestion and gain (Hancock and Behnke, 2001). In addition, particle size reduction allows a more uniform mixing of grain with protein, vitamin and mineral supplements, and helps to prevent sorting of ingredients when the mixture is fed to the animals. Feed to be pelleted should be ground finely.

As particle size is reduced, the incidence of gastric ulcers increases in pigs, especially with some grains such as barley. Thus particle size should not be smaller than 700–800 μm (0.7–0.8 mm). Research at the University of Guelph has shown that feed with a particle size of 550 μm produced ulcers in 90% of pigs within only 2 weeks (Friendship, 1999). Feed particle size is one of several important factors in the development of gastric ulcers, which are now reported as being common in slaughter animals (Friendship, 1999). Friendship (2003) has postulated that the type of pig used currently in conventional production may be more prone to gastric ulcers and that finely ground, pelleted diets that result in improved efficiency of feed utilization and feed handling are ulcerogenic. Other factors also play a role. An empty stomach appears

Table 5.20. Example feed mixtures that meet the suggested dietary specifications for heritage-type starting pigs (10–20 kg).

	Example 1	Example 2	Example 3	Example 4
Ingredient, kg				
Wheat	249.5	300	355	414
Maize	100	246		
Wheatfeed	218		135	200
Full-fat soybeans	150		76	
Canola meal			75	81
Soybean meal	100	150	75	
Peas, field	100	100	142	200
Faba beans	50	50	150	
Sainfoin seed dehulled		100		
Whitefish meal				90
Potato protein		20		50
L-lysine HCl	0.5		1	
Ground limestone	12	12	11	3
Dicalcium phosphate	6	8	7	
Salt (NaCl)	4	4	4	2
Vitamin Premix	5	5	5	5
Trace mineral Premix	5	5	5	5
Total, kg	1000	1000	1000	1000
Nutrient analysis (calculated)[a]				
Digestible energy (kcal/kg)	3370	3390	3305	3300
Digestible energy (MJ/kg)	14.10	14.21	13.77	13.82
Metabolizable energy (kcal/kg)	3255	3253	3172	3168
Metabolizable energy (MJ/kg)	13.5	13.6	13.28	13.33
Crude protein (g/kg)	205	195	205	195
Lysine (g/kg)	11.2	10.9	11.0	10.9
Methionine + cystine (g/kg)	6.3	6.3	6.5	7.6
Calcium (g/kg)	7.2	7.3	7.1	8.7
Phosphorus (available, g/kg)	3.4	3.7	3.3	5.1
Sodium (g/kg)	1.8	1.7	1.7	1.8

[a]Cannot be guaranteed because of ingredient variability.

to be an important risk factor for the development of gastric ulcers (Friendship, 2003). In the southern USA, where summer temperatures are high and feed intake is reduced, there is a well-documented increase in the incidence of ulcer deaths (Deen, 1993). The most practical solution to preventing an empty stomach is to ensure there is no disruption in the feeding programme. In addition there is a strong genetic component to gastric ulceration. The heritability of gastric ulcers has been estimated to be 0.52 (Berruecos and Robinson, 1972), similar to that of some carcass traits. It will be interesting to note whether gastric ulcers are reported to a similar extent in organic pigs. To date no reports appear to be available. Some other research suggests that gastric ulcers in pigs may have an infectious component similar to peptic ulcer disease in humans.

A very small particle size also increases problems with feed bridging in bins and feeders.

Sieving tests to determine particle size range should be carried out regularly in order to check that the feed is being ground to the required degree of fineness and that no material is un-ground. Segregation problems can be avoided by processing grain so that it is comparable in particle size to other ingredients in the batch.

The particle size of grain processed in a hammer mill is affected mainly by the size of the screen used, although the speed of the

Table 5.21. Example feed mixtures that meet the suggested dietary specifications for heritage-type growing pigs (20–50 kg).

	Example 1	Example 2	Example 3	Example 4
Ingredient, kg				
Barley	155	300	400	400
Wheat	100	50		
Maize	100			100
Wheatfeed	268	286	202	122
Oats				50
Canola meal	100	100	150	100
Peas, field	100	100	150	100
Faba beans	100	86	71	
Ground limestone	12	12	10	12
Dicalcium phosphate	2	3	3	3
Salt (NaCl)	3	3	3	3
Vitamin Premix	5	5	5	5
Trace mineral Premix	5	5	5	5
Total, kg	1000	1000	1000	1000
Nutrient analysis (calculated)[a]				
Digestible energy (kcal/kg)	3200	3140	3120	3170
Digestible energy (MJ/kg)	13.34	13.14	13.14	13.29
Metabolizable energy (kcal/kg)	3044	3015	2995	3043
Metabolizable energy (MJ/kg)	12.74	12.64	12.5	12.78
Crude protein (g/kg)	179	177	172	166
Lysine (g/kg)	9.2	8.6	9.1	7.8
Methionine + Cystine (g/kg)	5.6	5.6	6.8	5.9
Calcium (g/kg)	6.5	6.8	6.3	6.6
Phosphorus (available, g/kg)	2.7	2.9	2.5	2.6
Sodium (g/kg)	1.4	1.4	1.3	1.3

[a]Cannot be guaranteed because of ingredient variability.

hammer mill and the flow rate also affect it. Lightly rolled or crushed wheat may improve feed intake and gains compared with ground wheat when included in mash diets for growing pigs. Rolled de-husked oats (groats) are desirable in baby pig diets because of their high palatability and digestibility.

Equipment suitable for accurately weighing and dispensing small quantities of ingredients should be available. Care is necessary in handling premixes. Before being added into the mix these should be admixed with ground cereal to make up at least 5% of the total mix. This is to ensure that the premix disperses uniformly through the mix.

Weighed amounts of ingredients should be used where possible. This helps to ensure that the ingredients are added to the mix in the correct proportions. Some types of on-farm feed mixing equipment are based on volume rather than weight. In these cases it is essential that the equipment be calibrated frequently to account for changes in bulk density of ingredients.

Mixing and further processing

The feed ingredients have to be mixed thoroughly before feeding, to blend the ingredients uniformly and ensure an adequate intake of nutrients by the animals. In using ingredients it is important to ensure that stocks are rotated correctly, those held longest being used first.

The manufacturers of the mixing equipment should be able to advise on optimum mixing time but tests should be carried out periodically as a check.

Table 5.22. Example feed mixtures that meet the suggested dietary specifications for heritage-type finishing pigs (50–100 kg).

	Example 1	Example 2	Example 3	Example 4
Ingredient, kg				
Barley	458	451	470	600
Wheat		125	279	149
Maize				
Wheatfeed	268	150		
Canola meal	100		100	125
Soybean meal		50		
Peas, field	150	100	100	100
Faba beans		86	25	
Ground limestone	10	12	9	10
Dicalcium phosphate	1	3	3	3
Salt (NaCl)	3	3	3	3
Vitamin Premix	5	5	5	5
Trace mineral Premix	5	5	5	5
Total, kg	1000	1000	1000	1000
Nutrient analysis (calculated)[a]				
Digestible energy (kcal/kg)	3100	3110	3160	3128
Digestible energy (MJ/kg)	12.99	13.05	13.22	13.11
Metabolizable energy (kcal/kg)	2855	2986	3034	3004
Metabolizable energy (MJ/kg)	11.99	12.54	12.72	12.59
Crude protein (g/kg)	155	156	148	146
Lysine	7.5	7.4	6.6	6.7
Methionine + Cystine (g/kg)	5.8	4.6	6.3	5.6
Calcium (g/kg)	5.5	6.1	5.4	5.9
Phosphorus (available, g/kg)	2.2	2.3	2.1	2.0
Sodium (g/kg)	1.3	1.3	1.2	1.2

[a]Cannot be guaranteed because of ingredient variability.

A general recommendation with vertical mixers is that about 15 min mixing time is adequate after the last ingredient has been added to the mixer. With horizontal and drum mixers the mixing time is shorter, about 5–10 min after addition of the last ingredient.

After mixing, the feed should be stored in a clean, dry container, to maintain quality and protect it from damp and insect and rodent infestation. Bulk storage bins need to be emptied completely at frequent regular intervals so that stale feed does not remain in the bin.

Feeder management also plays an important role in delivering quality feed to pigs. Feed becomes stale and of reduced palatability if allowed to remain in feeders for long periods. Feeders should be filled often enough to provide fresh feed at all times, unless restricted feeding is being used. Sufficient should be added every one to two days for young pigs and every day for lactating sows. The feeder openings need to be kept free of wet, soiled feed since this can lead to moulding.

Pelleting

The feed may be pelleted or cubed after mixing. The usual pelleting process involves treating ground feed with steam and then passing the hot, moist mash through a die under pressure. The pellets are then cooled quickly and dried by means of forced air. Sufficient water should be applied so that all feed is moistened. Optimum moisture content of a feed required for good pelleting will vary with the composition of the feed; however, a range of 150–180 g moisture/kg is usually desirable. Feeds containing a high concentration of fibre require a higher level of moisture while feeds low in fibre require less.

Pigs will readily consume a diet in either mash or pelleted form, therefore pelleting is generally not economic but does offer some advantages since the increased bulk density of the pelleted diets helps in feed handling and storage. Also wastage in feeding is reduced, of relevance when outdoor feeding is employed. Another benefit is the prevention of segregation, the separation of ingredients from the rest of the mix. This problem may occur during transport of the feed from the mixer to the feeder. The major factors involved in segregation are particle size, shape and density.

An advantage of pelleting is that it may improve intake and improve the efficiency of feed utilization, particularly with fibrous ingredients such as wheat milling by-products. Patience *et al.* (1977) found that pelleting improved feed conversion and energy digestibility of diets containing wheat shorts. Skoch *et al.* (1983a) observed similar results with pig diets containing wheat middlings, whereas only slight benefits were obtained with a pelleted maize/soybean meal diet (Skoch *et al.*, 1983b). Improvements in feed efficiency reported in other studies range from 3 to 10%, due to improved digestibility of nutrients and reduced feed wastage (Hancock and Behnke, 2001). A further advantage of pelleting is that it can help to reduce microbial counts in the feed.

Fig. 5.2. The provision of a feed mill helps the producer to ensure correct mixing of the feed ingredients.

Bioavailability of nutrients may be influenced beneficially or adversely by pelleting. For example, the availability of phytate phosphorus in grains was found to be increased by steam pelleting (Bayley *et al.*, 1975). On the other hand, there may be destruction of heat-labile nutrients and components, such as phytase enzyme in wheat or vitamin A.

Generally it is assumed that small pellets are required for young pigs and larger pellets for growing and finishing pigs. However Hancock and Behnke (2001) reviewed findings on this issue and concluded that pellets produced using a single die with 4–5 mm holes were satisfactory for young, growing and finishing pigs. The optimum pellet size for breeding pigs does not seem to have been established.

Normally the feed is preconditioned with steam before entering the pellet mill. Steam releases natural adhesive properties in feeds to facilitate pelleting. It softens ingredient particles, so that they can more readily bind with each other under pressure. Heat and moisture cause starch gelatinization, helping to bind the particles together, as well as improving starch and fibre digestion.

Some ingredients possess properties that aid the pelleting process. Wheat and wheat by-products contain endosperm proteins that allow the feed particles to bind well during pelleting. Wheat gluten, when moist, has a gum-like consistency. The endosperm proteins of triticale, rye and barley also react with water to increase viscosity, but those of maize, sorghum, millet, rice and oats do not (Cheeke, 1991). The glucans and pentosans in barley, rye and oats have viscous properties when wet, improving pellet quality. Fat added at levels above 50 g/kg tends to cause pellet crumbling.

Pellets must be cooled and dried to safe moisture content as rapidly as possible after processing, using air cooling.

Extrusion of mixed feed has been found beneficial in improving digestibility. However, the process is generally limited to pet and fish feeds because of cost. Pelleting or extrusion of mixed feed has additional benefits relating to environmental and consumer safety aspects. As reported by Lucht (2002), nitrogen output in manure of young pigs was reduced by six percentage units and total output of manure per day by 510 to 486 g following extrusion of a diet containing 300 g wheat bran/kg. Coliforms, *Escherichia coli*, salmonella and moulds were eliminated by the extrusion process.

Pellet binders

Diets based on ingredients such as maize and soybean meal are difficult to pellet, especially when fat has been added, and a pellet binder may have to be included in the formula to achieve acceptable pellet quality. Pellet binders are permitted in organic diets and producers should check on those that are acceptable. Producers mixing feed soon learn which formulations are difficult to pellet. Inclusion of wheat or wheat by-products at levels of more than 100 g/kg diet should generally result in good pellets and avoid the need for a pellet binder. The type of binder approved for organic use is colloidal clay, with inclusion levels of around 5–12 kg/t. Some forms of clay have been shown to be effective in binding aflatoxin. Molasses can also be used as a pellet binder. Unlike other binders molasses also contributes nutrients to the diet therefore inclusion levels of 20–50 g/kg may be beneficial.

While all types of heat processing have beneficial effects on the feed it needs to be recognized that some destruction of nutrients may occur, particularly of some vitamins and AA (Table 5.23; Coehlo, 1994). For most vitamins, pelleting can be expected to result in an 8–10% loss of potency. Extrusion however, which usually employs much

Table 5.23. Losses (%) of vitamins during feed processing (from Coehlo, 1994).

Vitamin	Pelleting (82°C, 30 s)	Extrusion (120°C, 60 s)
Vitamin A (beadlet)	7	12
Vitamin D_3 (beadlet)	5	8
Vitamin E	5	9
Thiamin	11	21
Folic acid	7	14
Choline chloride	2	3

higher temperatures, can lead to a 10–15% loss of most vitamins.

Quality Control

Quality control is a way of ensuring that ingredients are of an acceptable quality, so that mixed feeds are of the required nutritive value and contain minimal or zero levels of contaminants. It is also a way of ensuring that ingredients that are not to be used immediately can be stored without risk of deterioration. Quality control is particularly important in the production of organic feed, since the ingredients used are often more variable in composition than regular feed ingredients.

The ingredient buyer must ensure that acceptable quality is a prerequisite when ingredients are to be purchased. A quality control protocol must be drawn up and followed as each batch of feed ingredients is received at the feed plant. Ingredients grown on the farm should be analysed periodically and purchased ingredients should (where possible) be accompanied by a guaranteed analysis.

Ingredients and any accompanying documentation need to be examined when they are received at the feed mill to ensure that the products meet organic standards. Each ingredient needs to be inspected visually for evidence of dampness, the presence of deleterious substances such as stones and soil, and storage pests. The moisture content of cereals should be determined by a moisture meter. Any batch containing more than 120–140 g moisture/kg should be rejected unless it can be dried to this level of moisture or less. This is to prevent spoilage during storage.

Every quality control programme should include periodic laboratory analysis of ingredients and mixed feed. Care should be taken to ensure that samples are representative, by taking samples from various points in the batch, mixing them and then drawing a sub-sample of 500–1000 g for analysis. For bagged material a common approach is to collect a sample with a probe from 10–15% of the bags in the batch. It is advisable to use only one-half of the sample for laboratory analysis and to retain one-half as a back-up in case of subsequent problems, discrepancies or disputes.

Tests

A fairly standard analysis conducted on feed ingredients is to determine the moisture, CP, oil, CF (or ADF and NDF) and ash (mineral matter), using approved chemical or physical methods. The results (so-called proximate composition) indicate whether the feedstuff meets acceptable guidelines. It will not be possible to analyse all batches of ingredients. Only periodic tests will be possible.

Additional tests may be carried out, for instance to determine the ratio of ash soluble and insoluble in acid, which indicates the amount of sand or soil contaminating the feed. This is a useful test for root crops such as cassava.

It may also be necessary to determine the free fatty acid content of oily materials as an index of rancidity, since this will affect palatability. Analyses of AA can only be conducted in specialized laboratories and are done less frequently. Instead most feed mixers (including commercial feed manufacturers) use procedures such as prediction equations based on the protein content of the sample to estimate the content of important AA. Tests for minerals are more routine, and offered by most laboratories. Tests for vitamins are offered by certain laboratories but are not very frequent since commercial feed manufacturers often disregard any vitamin contribution from the dietary ingredients and add all the necessary vitamins in the form of a supplement.

Tests for mycotoxins may be required if harvesting conditions or clinical signs are indicative of possible mycotoxin contamination. Regular tannin analyses are advised in countries that use high-tannin sorghums.

A suggested schedule of analyses for complete feeds and individual ingredients is as follows:

Each new batch of grain should be sampled (usually only for DM and CP) to assess variability. It is also advisable to analyse, and store separately, harvested grain from different fields since there may be differences due to soil type, fertilizer programme, seed variety, planting and harvesting conditions. Otherwise all the grain should be blended. Ingredients such as purchased soybean meal do not have to be sampled as frequently because processors are required by law to meet a guaranteed analysis on feed tags. A check once every three months for DM and CP may be sufficient. Commercial laboratories can analyse for the presence and concentration of mycotoxins, if suspected.

Each shipment of supplement and premix should be sampled and the samples stored in a freezer. If problems are found with the premix a sample is then available for analysis. Selected nutrients such as biotin or vitamin E can be chosen as monitors of correct composition.

- Mixed feed should be sampled and analysed at least every 2–3 months for DM, CP, calcium, phosphorus, and diet particle size (mash diets). In general, tests should be carried out frequently if problems persist, less frequently when no problems occur.

In interpreting the results of a laboratory test it should be noted that chemical analyses are subject to variation. Acceptable variation in laboratory analyses is presented in Table 5.24 (AAFCO, 2005). If the report indicates that a particular nutrient concentration is outside the range of normal variation, then a back-up sample should be submitted for analysis. If a repeated analysis of the same feed confirms the discrepancy, then it is likely that an error occurred in formulation, mixing or sampling. Producers may need to consult a nutritionist for advice in correcting the problem.

Producers using purchased complete feed do not have to pay as much attention to quality control. Feed manufacturers are required by feeds legislation in most countries to supply feed of a high standard, which requires them to test ingredients and finished products routinely. In addition, regulatory officials check commercial feeds at random for label compliance. However, it is still advisable for the organic producer to carry out routine checks on any purchased feeds and to communicate regularly with suppliers to ensure that the purchased products meet the standards expected.

Sampling

Samples for laboratory analysis need to be representative. The easiest way to take a representative sample of grain grown on the farm is to take it during harvest. Several 500 g samples should be taken from each truckload and bulked. The bulk should then be mixed thoroughly and a 500 g sample drawn. Mixed feed should be sampled as it is discharged from the mixer, bulked and sampled as with grain.

Small production units without access to laboratory facilities should seek the help of feed suppliers in carrying out periodic analysis of ingredients. Other agencies such as government, university or commercial laboratories may have to be used.

When pellets or crumbles are produced some physical testing is desirable to ensure that they are of the correct degree of hardness, i.e. they should not be so hard as to cause feeding difficulties, and they should

Table 5.24. Accepted analytical variation in nutrient analyses of feeds (adapted from AAFCO, 2005).

Nutrient	Analytical variance	Target value	Acceptable range
Crude protein	20/x + 2[a] (%)	10%	9.6–10.4%
Lysine	20%	0.7%	0.56–0.84%
Calcium	14/x + 6 (%)	0.8%	0.51–0.79%
Phosphorus	3/x + (8%)	0.5%	0.44–0.56%
Zinc	20%	100 ppm	80–120 ppm

[a]Where x (expected value) = 10% for crude protein, 0.8% for calcium and 0.5% for phosphorus.

not be so soft as to lose their structure during handling. Laboratory instruments have been designed to test the resistance of pellets to abrasion. After tumbling for a set period, a sieving operation determines the proportion of material still in pellet form. In most cases, however, pellet quality can be estimated by tests based on practical experience.

Quality control for mycotoxins

Mycotoxins are estimated to affect as much as 25% of the world's crops each year (CAST, 1989; Pasteiner, 1997; Devegowda *et al.*, 1998). Both cereal and protein crops can be affected. For instance, groundnuts are susceptible to aflatoxin contamination. Mycotoxins cause significant economic losses in animal agriculture worldwide. These fungal toxins are particularly important because they can be transmitted from animals to humans in milk or in meat products and because some of them are potent carcinogens and teratogens (Hesseltine, 1979). Therefore it is important to keep them out of the food chain and procedures to minimize the risk to animals and humans form an important part of the feed quality programme.

Mycotoxin contamination occurs sporadically, both seasonally and geographically (Pier, 1981; CAST, 1989). Some areas are at a higher risk for specific mycotoxins than others because of local conditions such as early frost, drought and insect damage (Osweiler, 1992). Table 5.25 shows the mycotoxins that may be found in feeds that come from different global locations. They occur naturally in a wide variety of crops used as feedstuffs. However, only the following mycotoxins occur significantly in naturally contaminated feeds: ochratoxin A, patulin, zearalenone, trichothecenes, citrinin and penicillic acid (Jelinek *et al.*, 1989). Blending of grains, damage in transit and improper storage conditions can lead to increased contamination. High concentrations are found in damaged, light or broken grain such as occur in screenings (Osweiler, 1992). Grain that is above optimum moisture content for storage may continue to respire and produce water. This increase in moisture in portions of a storage bin can encourage mould growth and toxin production. Alternating warm and cool weather conditions can favour water migration and condensation within a storage bin, again creating conditions favourable for local mould growth and toxin production (Osweiler, 1992). For these reasons it is very important that grain is stored at a moisture content not exceeding 140 g/kg and preferably in insulated storage bins. Susceptibility to mould growth increases when grains are ground, because the protective seed coat is broken. For this reason, care should be taken that ground pig feeds are stored in cool dry areas (Osweiler, 1992). Most mycotoxins are chemically stable and persist long after the fungi have died (Pasteiner, 1997). Storage fungi may be pathogenic or saprophytic, including the genera Aspergillus and Penicillium which produce many of the mycotoxins that are important in pig production and which can grow at moisture contents ranging from 140 to 180 g/kg and at temperatures that range from 10 to 50°C (Osweiler, 1992).

Table 5.25. Geographic occurrence of mycotoxins.

Location	Mycotoxin
Western Europe	Ochratoxin, vomitoxin, zearalenone
Eastern Europe	Zearalenone, vomitoxin
North America	Ochratoxin, vomitoxin, zearalenone, aflatoxins
South America	Aflatoxins, fumonisins, ochratoxin, vomitoxin, T-2 toxin
Africa	Aflatoxins, fumonisins, zearalenone
Asia	Aflatoxins
Australia	Aflatoxins, fumonisins

Effects of mycotoxins on pigs

Aflatoxin causes anaemia and stunted growth in pigs when present at 200 μg/kg. The US FDA guidelines allow no more than 20 μg aflatoxin/kg in animal feeds. Zearalenone and vomitoxin (deoxynivalenol) are produced by fusarium moulds and commonly are found in grains, primarily maize. Fusarium mould can be identified by a white to pink discoloration of grain. Zearalenone has oestrogenic properties that cause swelling of the vulva and teats of immature gilts when present at levels greater than 1 mg/kg. Vomitoxin causes feed refusal when present at 0.5 mg/kg. Vomiting will occur at much higher concentrations of vomitoxin.

The presence of mould does not always mean that mycotoxins are present. Feed refusal or very low feed intake suggests the presence of vomitoxin. Near normal feed intake but swelling of vulvas and mammary systems after 2 or 3 days suggests zearalenone contamination.

Routine testing for mycotoxins is helpful in managing the risk of contamination. As recommended by Lawlor and Lynch (2001), a routine analysis should test for aflatoxins, zearalenone and vomitoxin.

Dealing with mycotoxin contamination

Blending contaminated feedstuffs with uncontaminated feedstuffs to dilute the concentration of mycotoxin and the use of binding agents (such as bentonite clays and yeast MOS) might be used to lower the risk of mycotoxicosis, if acceptable to the local organic certifying agency. Binding agents such as bentonite, aluminosilicates, spent canola oil, bleaching clays and lucerne fibre have been used in feeds containing mycotoxins to prevent intestinal absorption of the toxins (Smith and Seddon, 1998). Even if effective, a binding agent is likely to be effective only against a specific mycotoxin. The absorbing clays or binding agents may also bind vitamins making them unavailable for absorption (Dale, 1998). Modified yeast cell wall extract (MOS) has been reported to effectively bind aflatoxin, and to bind ochratoxin and the fusariotoxins to a lesser degree. This product has advantages over other binding agents in that it does not bind vitamins or minerals (Devegowda *et al.*, 1998).

Preventing mould growth and subsequent mycotoxin production during storage of feedstuffs is a more certain way to avoid problems, as recommended by Lawlor and Lynch (2001). Cleaned grain should be stored at a moisture content of less than 140 g/kg in clean, preferably insulated, bins. If grain must be stored at higher moisture content or if storage conditions are poor, then a suitable mould inhibitor (e.g. propionic acid) should be used, if permitted under the local organic regulations.

If mycotoxicosis is suspected, the source of feed should be changed immediately. This should be followed by a thorough inspection of feed and grain storage bins, handling equipment, mill and feeders. Caked and/or musty feed should be removed and the equipment cleaned. The plant should be washed with a dilute solution of hypochlorite to reduce the fungal load (Lawlor and Lynch, 2001).

Mycotoxin residues in animal products

Many mycotoxins become concentrated in the meat and milk of animals and can pose a threat to human health. Denmark has legal regulations for maximum levels of ochratoxin in pig meat. When levels reach 10–15 μg/kg (ppb) in liver or kidney these organs are condemned, and when levels exceed 25 μg/kg (ppb) the entire carcass is condemned. These limits have been set because of the link between ochratoxin and human kidney disease (Devegowda *et al.*, 1998). Limits have also been set on aflatoxin contamination, because of its connection with liver cancer. The EU regulation (European Communities, 1998) set limits of between 5 and 50 μg/kg (ppb) for aflatoxin B1 in animal feedstuffs, depending on the feed ingredient and the animal for which the feedstuff is intended. The limit for a complete feedstuff for pigs or poultry is 20 μg/kg (ppb).

Methods of Feeding Pigs

Various feeding methods are used to control the intake of nutrients and influence growth, production and reproduction. Methods of feeding pigs may differ according to age, genotype, etc. Therefore an outline of some of these methods follows.

Full feeding

Ad libitum feeding involves providing pigs with free access to all the feed

Fig. 5.3. Have you tried any of this organic feed? It's yummy.

they want to consume. Full feeding from self-feeding hoppers has certain advantages. It reduces labour costs, makes feeding management somewhat simpler and maximizes growth rate. However, there are disadvantages. If pigs tend to deposit fat early, carcass grades will be reduced. Maximum intake of feed will be reduced if feed is allowed to become stale or is fouled, or if trough space is inadequate and causes competition for the available feed. Therefore good management is required to eliminate these problems. When self-feeders are used, care must be taken to ensure they are adjusted properly to prevent waste. Young growing pigs use feed economically. They should be encouraged to eat as much as possible. The breed of pigs being raised, previous market grades and production costs will determine whether restricted feeding may be more economical once pigs reach about 60–70 kg live weight.

Restricted feeding

Restricted feeding involves feeding less feed than the pigs can consume, and has advantages with types of pig that become too fat to meet the desired carcass grade. Restriction is accomplished usually by reducing the amount of feed provided or by reducing access time to the feeders. Adding fibre to the diet to dilute the concentrations of nutrient and to provide gut-fill is another approach. Restricted feeding is recommended for bred gilts and sows to prevent them becoming too fat. Overfeeding breeding stock is economically inefficient since it can reduce litter size and increase baby pig mortality. Restricted feeding of growing and finishing pigs is generally not recommended. Although grades may be improved, the additional cost of slower gains, increased labour and lower throughput offset the benefits of improved grades. If animals are to be limit-fed, restriction should not begin until they weigh at least 60 kg and feeding levels should not be below 85% of full feed intake.

Gilts grow slightly more slowly than castrates but produce leaner carcasses. Castrates tend to fatten at an earlier age and more rapidly than females, so restricted feeding can improve carcass quality of castrates. However, the reduced gain and longer time to market weight (from 7 to 14 days) must be balanced against the value of leaner carcasses. If possible, gilts and castrates should be divided into separate pens, with the gilts fed *ad libitum*.

Phase (stage) feeding

Dietary requirements change as pigs grow and it would be inefficient and uneconomical to feed the same diet to pigs during the entire life cycle. Phase (or stage) feeding refers to the use of different diets in the different phases or stages of the pig's life, i.e. starter, grower, finisher, gestation, lactation.

Liquid feeding

Liquid feeding is used when feed is mixed with water or other liquids such as skimmed milk or whey prior to feeding. Producers with a ready access to liquid by-products from milk processing or cheese manufacturing plants may prefer this system. In several studies liquid feeding has increased feed efficiency and improved rate of gain. These advantages may have been due to increased feed intake, reduced feed wastage and less lung irritation than with dry, dusty diets.

Feeding Newborn Pigs

Correct feeding is just one facet of a management strategy to ensure the successful weaning of large litters of healthy pigs. Gilts and sows often lose 25% of their pigs during the period from birth to weaning. About 7% of all pigs born are stillborn or die within the first few hours, and another 18% die between then and weaning. The first 3 days of life are critical and 65% of the deaths occur at this time, many from crushing by the sow. Careful supervision can save many of the pigs born alive. Orphan or weak piglets can be hand-fed on cow colostrum, cow's milk, goat's milk or commercial milk replacer, provided the procedure is acceptable by the organic certifying agency. As stated previously, baby pigs are born without antibodies to protect them against diseases in the environment of the farrowing pen. Colostrum contains antibodies that help protect the baby pigs until they can produce their own antibodies by 3–4 weeks of age. Their ability to absorb antibodies into their bloodstream begins to decline soon after birth; therefore it is important to ensure that the piglets consume as much colostrum as possible within the first few hours. Chilling is another important contributor to piglet mortality and needs to be prevented. It makes the piglet weak and sluggish, leaving it vulnerable to other dangers such as crushing and starvation. Some producers use batch farrowing to reduce piglet mortality. When sows and gilts farrow in batches, it is possible to equalize litters and adjust litter size to the number of functioning teats and to the nursing ability of the sows. Pigs can be transferred from sow to sow up to about 3–4 days after farrowing. Multiple suckling is also common. Under this system, sows and litters run together in groups of four to six sows. The age difference between litters should not be more than 1 week. This accustoms the pigs to mixing with other litters and minimizes aggression from mixing. Also it helps to ensure an adequate intake of milk by each piglet.

Since the baby pig grows very quickly, its blood increases rapidly in volume. Consequently, it must have an adequate supply of iron. Sow's milk contains little of this mineral and supplementing her feed with increased levels of iron does not greatly increase the concentration in her milk. To prevent anaemia, the baby pig needs to receive supplemental iron within 3 days of birth. Iron supplementation is very important for the baby pig, to prevent problems of poor growth, listlessness, rough hair coat, etc. A characteristic sign of anaemia is laboured breathing after minimal activity ('thumps'). Organic producers usually provide sods of earth in the farrowing pen for the baby pigs to root and obtain a supply of iron. It is important that the sods be free of disease organisms and parasites. Iron supplementation of creep-feed and starter diets is necessary for piglets raised outdoors in yards. Diets fed to older animals usually contain adequate levels of iron.

Milk production of the sow depends on the individual, lactation number, litter size and stage of lactation. After about 3 weeks, milk production starts to decline and there is a nutrient deficit period unless creep-feed is provided to allow the young pig to adapt to solid feed and be weaned. The stomach capacity of the young pig is low, therefore a diet of high nutrient density should be used to assist nutrient intake. The natural age of weaning is around 56–70 days and in organic production it is at least 40 days. Creep-feed has to be formulated carefully from highly digestible ingredients since at an early age the gut has not yet adapted to non-milk diets. Also, the stomach capacity of the young pig is low. Indigestible feed is likely to result in digestive upsets and scouring. Consequently it is recommended that producers purchase creep-feed rather than attempt to mix it on the farm.

This diet should contain 200–240 g protein/kg (11–14 g lysine/kg) and include milk products among its ingredients. Some producers sprinkle dry powdered milk on the creep feed to improve its smell and palatability. This diet may be offered as small pellets or crumbles to stimulate consumption.

Social interaction between the piglets while eating is important in developing feeding behaviour. A well-designed feeder without solid partitions encourages good social interaction and maximum feed intake, yet preventing the small pigs from lying and dunging in the feeders.

After about 5–6 weeks the piglets should weigh about 12–15 kg and can be gradually switched over to a starter diet. This diet can be mixed on the farm and is more economical, being lower in nutrient content and in digestibility than creep-feed. The starter diet introduced while the piglets are still suckling should be continued after weaning until the piglets have reached an average weight of about 25 kg, then mixed with grower diet for a few days before switching completely to a grower diet.

Feeding Weaned Pigs

The creep-feed used when the piglets are still suckling should be continued after weaning for the length of time recommended by the feed supplier. Weaning is a stressful event for the young pig, commonly resulting in a ‘post-weaning lag’ when the young pig fails to grow for some time and may even lose weight. Some pigs will not eat after weaning for up to 3 days whereas other littermates will eat almost immediately. This variation decreases as the pigs become older. Failure to eat is often followed by over-consumption of the weaning diet if it is available *ad libitum*, leading to digestive upsets. However, by 40 days of age it should be possible to wean the pigs successfully, since the stress of weaning diminishes as the pigs become older. Other strategies that help include moving the sow out of the farrowing pen (rather than the reverse) and leaving the young pigs there for a few days before moving them to the rearing accommodation. Having the pigs eating sufficient creep-feed daily will ensure that they are accustomed to solid feed at weaning. Also the feed should be attractive and of high nutrient quality to ensure high digestibility. Once the pigs are eating successfully they can be gradually introduced to a starter diet which can be a 50:50 blend of creep-feed and grower feed and fed until the pigs reach 20–25 kg live weight. It does not have to be pelleted if meal-type diets will be fed during the growing and finishing stages. The feeder should be of a design that allows easy access by the pig and producer, stays relatively clean and can be placed securely inside the creep area. The natural inclination of a pig is to root or seek feed on a flat surface and most feeders are designed to accommodate this behaviour.

Careful attention needs to be paid to hygiene and avoidance of disease at this time. Digestive upsets immediately post-weaning increase susceptibility to disease. The pen needs to be warm and draught-free.

The most suitable starter diet is one containing feed ingredients which ensure that it is palatable, highly digestible, low in anti-nutritive factors, has a moderate protein content of high quality and has a high content of digestible energy. High digestibility of fat, protein and carbohydrate in the starter diet are important to avoid digestive upsets while the gut adapts to a dry diet. Some producers feed the diet as gruel for the first few days, to ease this transition. Very high protein diets (>20% CP) may increase digestive upsets. Some research has suggested that certain protein sources (especially soybean meal) may aggravate weaning problems, but this does not appear to be a major problem if the proteins have been heat-processed. The correct choice of sources of fibre and complex carbohydrates helps to ensure the functional development of the digestive system and the gut microflora. These include oligosaccharides and wheat fibre ingredients. Sow's milk is very high in fat (>300 g/kg DM), yet commercial starter diets with similar fat levels are likely to produce digestive upsets. This is probably related to the fatty acid composition of the fats used. Improved feed intake immediately post-weaning can be achieved by the use of liquid or gruel feeding as opposed to dry feeding. Also, an adequate intake of clean water is important in helping to ensure an adequate feed intake.

Feeding Strategy for Market Pigs

Feed accounts for about 70–80% of the total costs of producing market animals, therefore the diets used for growing-finishing pigs and the feeding regimen should be designed to optimize use of the feeds available and profitability. The requirements for energy and protein change as the animals grow, the requirement for protein in relation to energy decreasing over time. As a result, it is advisable to use several diets over the period from weaning to market at around 100 kg live weight. It is common to use a three-stage feeding programme: i.e. starter diet from weaning to about 20–25 kg, grower from then until the pigs reach about 50–60 kg, followed by finisher from then until market. Usually these diets are fed *ad libitum*, for maximum efficiency. Pigs that are likely to be too fat at market because of their genotype (especially castrates) should be placed on a restricted scale of feeding during the finisher stage. Penning by sex may have to be used to achieve this objective. Gilts usually grow more slowly than castrates because they eat less, particularly above 50 kg body weight. They generally deposit the same amount of lean tissue per day as castrates but deposit less fat because of their lower energy intake. Gilts are therefore somewhat older and leaner by the time they reach market weight. Because of a lower feed intake but a similar accretion of lean tissue, gilts require a higher concentration of dietary AA than castrates. Consequently, it is desirable to feed gilts and castrates in separate pens. Split-sex feeding allows for the more precise formulation of diets to meet the nutrient needs of castrates and gilts. Also, gilts may exhibit oestrus in the finisher pen before they reach slaughter weight, which can affect the feed intake and growth of the other animals. Separation of pigs by sex to different pens at weaning or at the start of the grower period allows the producer to market leaner gilts and to feed castrates more economically. It also results in pigs of a more uniform weight within each pen. In conventional production it is fairly common to have separate gilt and castrate diets for use during the final stage of finishing.

Feeding Breeding Gilts and Sows

In conventional herds the breeding gilts are often housed separately from the market pigs from about 70 kg live weight so that they can be fed differently. The purpose is to allow the breeding gilts to grow at a slower rate than gilts reared for slaughter and give them time to build up fat reserves while continuing to deposit lean tissue. This strategy is considered important for the development of the reproductive system and the longevity of the sow. However, the diets used usually contain higher concentrations of calcium, phosphorus and micronutrients than in finisher diet, and may not be acceptable to organic producers.

A simpler approach, which is favoured by many organic producers, is to use finisher feed until the gilts are bred at second or third oestrus. Breeding at third oestrus is advisable for two reasons: the ovulation rate is higher than at pubertal oestrus and since the gilts are larger and heavier at this stage they are better able to support the weight of a boar during natural mating (minimizing the need for artificial insemination).

It is difficult to achieve the target nutrient intakes in pregnancy and lactation with the same dietary mixture. Using a single diet can result in overfeeding of energy and protein in pregnancy and underfeeding of energy and protein in lactation. However, if it is not possible to use two diets then lactation feed should be used during both gestation and lactation. Where possible, a low-density, dry-sow diet and a separate high-density, lactating-sow diet should be used.

The daily ration up to 2–3 weeks before mating is usually around 2 kg/day, and from then until mating it is customary to increase the ration to about 3.5 kg/day or to feed *ad libitum* to achieve a flushing effect on ovulation, with a view to increasing litter size. Flushing has been shown to be effective at the second or third oestrus. However, Kirkwood *et al*. (1988) showed that use of a flushing nutritional regime in the prepubertal period did not enhance piglet production from gilts mated at puberty. After mating the strategy is to achieve a steady increase in maternal body weight. From late pregnancy it is advisable to increase the feed allowance because two-thirds of the piglet's body weight is gained during the last third of the gestation period.

A common feeding programme for gilts and sows after breeding is as follows, based on a diet of gestation feed:

- Day 1 (day of breeding) to day 30: 2 kg feed per sow per day.
- Day 31 to day 80: variable amounts of feed depending on body condition.
  - Normal condition: 2 kg per sow per day.
  - Thin: 3 kg per sow per day.
  - Very thin: 4 kg per sow per day.
- Day 81 to day 107: increase the ration of all animals to allow for increase in weight of developing fetuses.
  - Normal sow: 3 kg per sow per day.
  - Thin sow: 4 kg per sow per day.
  - Very thin sow: 5 kg per sow per day.

A common scale for assessing the body condition of sows is as follows.

1: Very thin, hips and backbone very prominent, no fat cover.
2: Hip bones and backbone easily felt with no pressure.
3: Firm pressure required to feel the hip bones and backbone.
4: Impossible to feel bones with pressure on palm of hand.
5: Visually very fat, impossible to feel bones with pressure from a finger.

Conventional producers try to achieve a condition score of 3–3.5 during the dry period and a minimum of 2.5 at weaning. Similar targets are suggested for organic producers, although the breeds used are commonly fatter. The longer milking period of organic sows may in some cases make the targets harder to achieve, in which case the ration has to be increased. If they are too thin they are receiving too little feed, and if too fat they are receiving too much.

One week before farrowing the animals should be washed and transferred to the farrowing quarters to allow for adaptation to the new surroundings and minimize stress during farrowing. The ration should be decreased gradually to 1 kg/day just before farrowing. Producers often supplement the diet with bran or whole oats before farrowing, to reduce constipation and resultant problems during farrowing.

The following can be used as a practical guideline for feeding lactating sows. The exact intake of feed will vary according to the energy concentration of the diet, number of feedings per day, genotype, feed quality and environmental factors. The aim is to encourage the sow to eat as much feed as possible early in lactation to support high milk production and avoid loss of condition. One successful feeding programme allows a ration of 1 kg feed plus 0.5 kg bran or oats on the day after farrowing, followed by a gradual increase in the feed allowance to *ad libitum* feeding by 10–12 days after farrowing. If intake remains low and the sow is losing too much condition it may be possible to encourage a higher intake by feeding the sow three or four times a day.

It is recommended that *ad libitum* feeding of lactation diet be continued after weaning until the sow is re-bred, to restore body condition. After re-breeding the sow should be switched to gestation feed and fed rationed amounts according to body condition.

Adjusting the feeding programme for sows

If the sows are too fat the feed intake is too high or the diet is too high in nutrients. The feed allowance has to be reduced during the gestation period, or lower nutrient specifications have to be used in formulating the diet. Alternatively the diet can be diluted with a fibrous, bulky ingredient such as bran or chopped straw. If the sows are too thin the feed allowance has to be increased or the nutrient specifications for the diet have to be increased.

A more specialized feeding strategy for breeding sows

Producers using modern hybrid animals may wish to adopt the following feeding regimen, after discussion of the details with the breeding company:

- Phase 1, 35–70 kg: a medium-density finisher diet fed *ad libitum*.
- Phase 2, 70 kg–21 days pre-mating: a specialized gilt-rearing diet fed at 2.5–3.0 kg/day.
- Phase 3, 21 days pre-mating to mating: a specialized gilt-rearing diet fed *ad libitum*.
- Phase 4, mating to late pregnancy: a specialized gilt-rearing diet fed at 2.0–2.5 kg/day.
- Phase 5, late pregnancy to weaning: a lactating-sow diet fed to appetite.
- Phase 6, weaning to re-mating: a specialized gilt-rearing diet fed *ad libitum*.

Feeding Boars

Because growing boars need to deposit appreciable amounts of protein, they should be maintained on a finisher diet until used for mating. Thereafter they can be fed a diet similar to a sow gestation diet since the nutrient requirements are reported to be similar. According to the NRC (1998), a boar requires a 2 kg feed intake per day of a diet containing 130 g CP and 3400 kcal (14.23 MJ) DE per kg. In practice the daily feed allowance should be based on the physical condition of the animal and be adjusted according to season, condition and workload. A body condition score of 3 on a scale from 1–5 (similar to the condition scoring system for sows) is considered desirable.

Newly introduced young boars are usually fed about 2.0–2.5 kg/day, the ration being adjusted up or down during the breeding period to maintain thriftiness and vigour. A ration of about 2.5 kg/day should allow the young animal to grow well to maturity and not become too heavy. The usual ration for a mature working boar with access to outdoors is 2.5–3.5 kg/day.

Wilson *et al.* (2004) reviewed findings on the nutrition of boars in conventional production for use in artificial insemination stations and reported that excess body weight is a major reason for culling boars. In a natural mating situation in which the boars are significantly larger than the gilts or sows, the females are not able to stand to maintain the weight of the boar during mating. Therefore a restricted feeding programme is necessary to minimize the weight gain of large boars and maintain their longevity in the herd.

Overfeeding and excess body weight contribute also to increased incidence of feet and leg problems as well as a reduction of libido. Stevermer *et al.* (1961) conducted a 15-month feeding trial with Yorkshire boars on three levels of nutrition: (i) *ad libitum*; (ii) moderately fed (100% NRC, 40.2 MJ DE/day); and (iii) restricted. The boars fed *ad libitum* gained the most weight (136 kg), the boars fed at the moderate level gained 37 kg, and the restricted-fed boars lost 60 kg body weight. In general fertility was only slightly affected by the level of nutrition. Other studies reviewed by Wilson *et al.* (2004) investigated the relationship between energy intake or total feeding levels on sperm production in the boar (Kemp, 1989). Three groups of Yorkshire boars were each fed: (i) *ad libitum* (74 MJ ME/day, 5.89 kg of diet); (ii) a moderate level (47 MJ ME/day, 3.74 kg of diet); or (iii) a restricted low level intake (25 MJ ME/day, 1.99 kg of diet) during a 12-week trial. There were no changes in sperm numbers during the first 6 weeks. However, significant differences were recorded at weeks 8 to 12 of semen collection, when sperm production decreased as feed intake levels changed from high to medium and medium to low. In another trial where two different genetic lines of boars were used, results showed that higher feed intake increased sperm production and libido in one genetic line but not in another (Boyd *et al.*, 1996).

Mycotoxins and boar fertility

It is necessary to store and handle feed ingredients properly to minimize the presence of moulds and mycotoxins, since the boar is one of the most sensitive animals to vomitoxin (Louis, 1996). Several field investigations have shown marked improvement in semen quality when sources of mycotoxins can be blended down (diluted) or eliminated (Wilson *et al.*, 2004). The addition of mould inhibitors and binding agents to boar feed is recommended where permitted by the organic regulations, to help protect against possible sources of contamination. An experiment reported by Wilson *et al.* (2004) involved three levels of zearalenone being fed for 8 weeks. There were no significant effects on semen characteristics or libido of the boar (Ruhr *et al.*, 1983); however, total sperm ejaculated decreased linearly with increasing amounts of zearalenone. Aflatoxin B1 is known to have a detrimental effect on semen characteristics and fertility.

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6

Choosing the Right Breed and Strain of Pig

The type of pig selected for organic production needs to do well under the conditions on the farm and produce meat of high quality at a profitable cost. Where acceptable under the local organic regulations, a pig of improved type (hybrid) should be first choice.

A wide range of genotypes of pigs is available for organic production internationally, displaying greatly different growth and carcass characteristics and responding differently to diet composition and level of feeding. Therefore the dietary regime and feeding programme should be modified according to the particular genotype of pig selected.

Use of older pure breeds allows the term 'original' or 'traditional' or 'heritage' to be applied to the meat products, which may be useful in marketing. These breeds may be better adapted to the region and may produce meat of better eating quality, but are likely to be unimproved in terms of growth performance and carcass quality. Therefore their meat may be produced at a relatively higher cost. An example is the Bísaro pig, which despite having lower growth rate, a less than ideal bodily conformation, and excessive adult weight and body size, is known to produce meat of excellent quality and suitable for processing (Santos e Silva *et al.*, 2000). Another example is the Krškopolje or the Blackbelted pig in Slovenia, which does not compare favourably with improved breeds in terms of growth performance and carcass quality but is reputed to have good meat characteristics. Breeds such as the Mangalitsa, bred in Eastern Europe, yield meat that is suited to the production of dried, smoked and fermented pork products and some breeds such as the Chinese Shandong have been shown to have a greater natural immunity to disease than some other breeds. A major European outdoor system is the traditional Mediterranean silvopastoral system. This system uses indigenous breeds that are pastured extensively in natural forests for the production of high-value, dry-cured hams. Typically, all phases of production take place outdoors, sometimes in extreme conditions in mountain zones. These animals reach their slaughter weight at an advanced age, conferring preferred attributes to the meat.

Sows

The traits important for a good outdoor sow include prolificacy, good conformation, strong vigour, good maternal behaviour including ease of handling, and adequate fat reserves in northern regions to provide against cold conditions. The sows used in Europe for outdoor production are commonly Saddleback, Landrace, Large White and Duroc crosses. Traditionally sows were of the Saddleback breed in the UK. Later the Saddleback × Landrace, known as the 'Blue', was used. Recently, Duroc crosses have replaced the Blue. The Duroc shares the same characteristics of hardiness and good mothering ability as the Saddleback but has significantly better growth and carcass characteristics.

Boars

Boars also need to be able to withstand the outdoor conditions, and to have the right temperament for group management when raised as meat animals. For the conventional market, boars are normally selected for lower backfat, to counter the backfat traits in sows. Conventional outdoor systems may use Duroc, Large White or even Sire Line boars to provide the traits for lean meat. Saddleback, Duroc and the Camborough 12 are recommended for organic production by some organic certifying agencies (Guy and Edwards, 2002).

Despite improved breeding and selection, the progeny from outdoor pig production systems in Europe tend to have increased backfat than equivalent pigs from indoor units, probably in response to the outdoor environment. This makes the choice of sire line very important.

Coloured breeds such as Durocs and Hampshires have greater resistance to sunburn than entirely white breeds, such as the Landrace and Large White. However, shade can be provided to mitigate the effect of sunburn.

Breed averages for sire lines in the US National Genetic Evaluation Program are shown in Table 6.1 (Mabry and Baas, 2001). In general, the sire lines that were superior in terms of tenth-rib backfat thickness and loin muscle area were not the most desirable in terms of meat quality traits. Conversely, the sire line that was superior for most quality traits (Berkshire) was the fattest and had the lowest area of loin muscle. Durocs were intermediate for backfat and loin muscle area and slightly below the Berkshire for meat quality traits.

Traditional breeds

Organic producers are encouraged to use traditional breeds which may be more suited to local conditions than improved genotypes. A large number of these breeds exists in several countries, though often in relatively low numbers. One disadvantage of using a pure breed on small farms is an inadequate size of the breeding herd, leading to the problem of in-breeding which results in loss of productivity in the stock.

Traditional breeds are currently well represented in smaller organic farms in the UK (ADAS, 2001), e.g. British Saddlebacks. Other examples are Gloucester Old Spots and Tamworths, both of which have the reputation of being hardy and excellent mothers. Large Blacks, Berkshires and Wessex Saddlebacks are being used in Australia.

Table 6.1. Breed averages for sire lines in the US National Genetic Evaluation Program. (From Mabry and Baas, 2001.)

Breed	Gain (g/day)	Lean gain (g/day)	Backfat, 10th rib (mm)	Loin muscle area (cm^2)	Intramuscular fat (%)	Drip loss (%)	Tenderness rating, 1–5
Berkshire	839	286	31.8	37.0	2.43	2.43	3.50
Danbred HD	830	327	24.9	43.5	2.61	3.34	3.45
Duroc	885	318	28.7	39.6	3.19	2.75	3.38
Hampshire	848	322	25.7	42.5	2.61	3.56	3.36
NGT Large White	848	295	29.7	36.3	2.25	2.92	3.16
NE SPF Duroc	894	331	29.2	41.0	3.30	2.81	3.36
Newsham	862	331	24.9	41.6	2.27	2.99	3.25
Spotted	835	286	31.5	37.6	2.65	2.88	3.16
Yorkshire	835	308	26.7	39.8	2.42	2.85	3.26

Cross-breds

Pigs should be cross-bred in order to obtain the full advantage of heterosis (hybrid vigour). Table 6.2 shows how the important production traits of pigs respond to genetic selection and cross-breeding.

This explains why it is important to use cross-breeding in sows to improve litter size and piglet weight and to use improved genotypes of boars to improve carcass quality.

In conventional production, the sow is commonly a crossbred (F1 generation) obtained from a crossing of selected animals of two pure breeds (e.g. Yorkshire – also known as Large White – × Landrace). These cross-bred sows are then mated to selected boars of a third breed such as Duroc or Hampshire to impart further heterosis and desirable carcass characteristics in the progeny (F2 generation) to be marketed as meat animals. The F2 animals do not enter the breeding herd.

The main objectives of a cross-breeding policy are to maximize three traits: sow productivity (number of pigs weaned or sold per sow per year), efficiency of gain (growth rates and feed conversion ratios) in the market pigs, and suitability of the carcass for the selected market (weight, length, fat depth/quality, skin and meat and fat colour). Implementation of this type of breeding policy, improved nutrition and the adoption of a carcass-value marketing system have led to a reduction of more than 50% in backfat thickness in conventional pig production and a simultaneous increase in lean meat content in several countries.

Table 6.2. How the important production traits of pigs respond to genetic selection and cross-breeding.

Trait	Genetic selection	Cross-breeding
Growth rate	Medium	Medium
Sow productivity	Low	High
Carcass quality	High	Low

It will be clear from this brief description of cross-breeding principles that only large organic units would be capable of producing such superior stock on a regular basis. A compromise would be to purchase boars and cross-bred gilts as required, within the limits imposed by the local regulations. Purchase of replacement breeding stock is therefore likely to remain a routine practice, particularly in smaller units. Another approach would be to use artificial insemination, where permitted under the local certifying regulations. Some agencies recommend that artificial insemination be avoided but its use is justified if the alternative is a marked degree of in-breeding, which is quite common in small (particularly closed) herds.

Rydhmer *et al*. (2014) evaluated the sustainability of breeding programmes in organic and traditional systems of pig production and

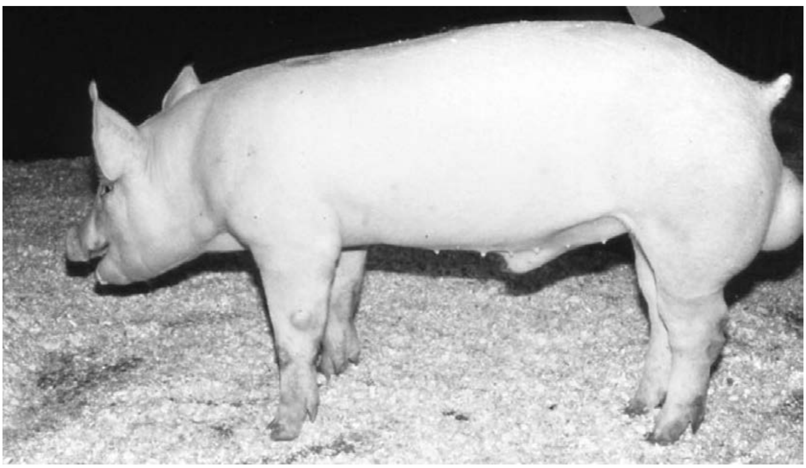

Fig. 6.1. Example of a boar line (Yorkshire also known as Large White) being used in organic production.

showed quite clearly that the small scale of organic systems makes it difficult to sustain an optimal breeding programme.

The breeding programme should aim at producing breeders and progeny that are suited to outdoor conditions, requiring the stock to be hardy.

Preferences for breeding goals in organic pig herds in Sweden were reported by Wallenbeck *et al.* (2016). Over 70% of farmers ranked piglet survival, fertility, sow longevity, leg health, feed conversion, piglet birth weight, piglet and slaughter pig growth as being of high or moderate importance. Parasite resistance and roughage consumption were also ranked highly, as well as improved health traits. A low priority was given to carcass quality and litter size.

Organic standards, in Europe at least, require the implementation of a closed herd policy. Consequently, only 20% of stock on an annual basis may be bought in and only if the stock comes from non-intensive units. Since it is usual for sows to produce only about eight litters before being culled, a replacement level of 30–40% per year is necessary to maintain the correct balance of young to old sows.

The benefits of cross-breeding in sows were demonstrated by Gaugler *et al.* (1984). Data on litter size and weight at 42 days and piglet survival to 42 days were collected from 366 litters of Duroc, Yorkshire, Spotted and Landrace sows, either pure-bred or cross-bred. Results were as follows for litter size, litter weight (kg) and survival to 42 days (%) respectively: Duroc 6.29, 70.30 and 67.80; Spotted 6.85, 74.26 and 74.25; Yorkshire 7.25, 73.53 and 64.21; and Landrace 7.88, 89.79 and 76.97. When cross-bred the average advantage over the pure-breds at 42 days was 0.79 more pigs, 11.72 kg extra litter weight and a 5.56% greater survival rate. The best overall productivity was from Duroc × Landrace sows, with litters averaging 97.99 kg at 42 days and a survival rate of 83.71% from birth.

Other researchers (Cassady *et al.*, 2002) reported similar effects on reproductive traits of Yorkshire, Landrace, Large White, and Chester White sows and their crosses (Exp. 1: 868 first parity litters) and Duroc, Hampshire, Pietrain, and Spot and their crosses (Exp. 2: 865 first parity litters). Heterosis significantly increased sow weight at 110 d of gestation and litter weight at 14 and 28 d (weaning) in both experiments. In Exp. 2 it significantly increased number of nipples, weight at puberty, lactation weight loss, litter size, and litter birth weight. The researchers also found that heterosis significantly increased the number of pigs per litter at 14 and 28 days and litter weights at birth, 14 and 28 days in Exp.1 but decreased litter size in Exp. 2.

McLaren *et al.* (1987) studied the extent of heterosis in the progeny of Duroc, Landrace and Spotted breeds and reported overall estimates of 0.07 kg/day for average daily gain (10.5%), 14 days less for age at slaughter (7.5%) and 0.83 mm less backfat in the carcass (3.2%).

Kongsted *et al.*, (2011) also reported that cross-bred sows show increased productivity and fertility, farrowing larger pigs with an increased rate of survival. The pigs are heavier at weaning and make more rapid gains from weaning to market.

Suggestions from some organic producers are that a Saddleback × Duroc cross-bred sow provides hybrid vigour and overcomes the Saddleback's disadvantages of lower litter sizes, increased carcass fatness and reduced feed conversion efficiency.

Saltalamacchia *et al.* (2004) suggested that Siena Belted, Casertana, Romagnola, Calabrian, Black Madonie, Duroc, Large White × Duroc and Large White × Siena Belted stock are suitable for organic production in Italy. Uremovic *et al.* (2003) found

Fig. 6.2. Another example of a boar line (Duroc) being used in organic production.

that Black Slavonian and F1 crosses with Duroc were suitable for European continental conditions and that German Landrace are suitable for Mediterranean conditions. Climate is therefore an important factor influencing breed selection for outdoor-based organic production.

Kelly *et al.*, (2007) investigated the effect of breed and husbandry system on performance and carcass quality of organic market pigs. The study compared performance and carcass quality of progeny from three maternal breed types which were kept either at pasture or in housing with an outdoor run and offered grain-based feed (no details) *ad libitum*, either alone or with fodder beet or grass/clover silage as additional forage. The sow breeds were 'traditional' (Saddleback; S), 'cross-bred traditional' (Saddleback × Duroc; SD) or 'modern' (Camborough 12; C12), and were all bred to Duroc boars. The pigs were weaned at 30 kg and grown to a slaughter weight of 90 kg. Live-weight gain, feed intake and the proportion of intake that was forages did not differ among genotypes. Carcass backfat thickness (P2) was lowest for C12 progeny, and highest for the progeny of the traditional pure breed (C12 = 11.4, S = 14.3, SD = 13.4) (Table 6.3). Intake of the forage supplements was very low when feed was available *ad libitum*. Over the whole period it averaged only 0.12 kg/day for the silage and 0.16 kg/day for the fodder beet, representing less than 2% of total DM intake. Growth rate did not differ between housing systems, but feed intake was increased in outdoor animals (OUT = 2.47, IN = 2.22 kg meal equivalent per day), resulting in a significant deterioration in feed conversion efficiency. Animals allowed access to grazing consumed a smaller proportion of their daily intake from the additional forages, and had a higher killing-out percentage.

Hence the breeding programme should aim at producing breeders and progeny that are suited to outdoor conditions, requiring the stock to be hardy. The Duroc breed remains one of the top choices in North America for a terminal sire line to use on sows that are crosses between the white breeds. Because the sire breed is different from the maternal breeds, hybrid vigour is at its maximum for the market pigs. This has a positive effect not only on growth rate but also on many other factors such as hardiness and resistance to disease. Hair colour should not be an issue for this type of mating. When crossed to F_1 sows from Yorkshire × Landrace breeds, Durocs almost always yield white market hogs since colour is a recessive trait.

Table 6.3. Effect of dam genotype on performance from 30kg weight to slaughter and carcass quality of growing pigs produced under organic standards (from Kelly *et al.*, 2007).

Parameter	Camborough 12	Saddleback	Saddleback × Duroc	Statistical significance of difference
Initial weight (kg)	31.5	31.8	28.9	NS
Final weight (kg)	90.7	89.7	87.1	NS
Daily gain (kg per day)	0.74	0.74	0.70	NS
Feed intake (kg meal equiv. per day)	2.33	2.37	2.33	NS
Feed conversion ratio	3.20	3.26	3.34	NS
Concentrate intake (kg per day)	2.31	2.33	2.31	NS
Silage intake (kg per day)	0.05	0.03	0.04	NS
Fodder beet intake (kg per day)	0.05	0.06	0.04	NS
Carcass weight (kg)	67.5	67.2	65.8	NS
Killing-out %	74.0	74.5	74.2	NS
Backfat thickness (mm P2)	11.4	14.3	13.4	***
Lean in carcass (%)	57.4	54.1	55.1	***

NS = not significant; *** = p<0.001.

Fig. 6.3. Example of a sow line (Saddleback), useful in a cross-breeding programme for organic production. (Copyright Rachel Wood.)

Exposure to Outdoor Conditions

Despite improved breeding and selection, the progeny from outdoor pig production systems in Europe tend to have increased backfat compared with equivalent pigs from indoor units, probably in response to the outdoor environment. This makes the choice of sire line very important.

Coloured breeds such as Durocs and Hampshires have greater resistance to sunburn than entirely white breeds, such as the Landrace and Large White. However, shade can be provided to mitigate the effect of sunburn. Saddleback, Duroc and the Camborough 12 are recommended for organic production by some organic certifying agencies.

Meat Quality

A review of the effects of organic production on meat quality of pigs was published by Blair (2011). Two main factors affect the meat quality, i.e. genotype and the organic feeding system.

Genotype

The relationship between genotype and eating quality of pork is important since it is accepted that the great advances which have been made since the 1960s in the production of leaner carcasses in conventional pig farming may have resulted in pork of somewhat lower eating quality (Wood and Cameron, 1994).

Ball (2000) reported the results of a large study on the four principal pig breeds in Canada (Yorkshire, Landrace, Duroc, Hampshire), in which their main growth, carcass and meat characteristics were evaluated. The stock came from 118 different breeding herds, representing 57 different seedstock producers and totalled over 2000 animals. Litter groups consisted of two boars, a castrate and a gilt. The test started when the average weight of the animals was 30 kg and was terminated when the average weight was 100 kg.

Significant differences were observed among breeds for most of the growth traits (Table 6.4). Landrace pigs had the fewest days to 100 kg and highest average daily

Table 6.4. Breed comparisons (litter groups consisted of two boars, a castrate and a gilt) for growth, carcass and meat characteristics (from Ball, 2000).

	Yorkshire	Landrace	Hampshire	Duroc
Growth trait				
Days to 100 kg	161.3[b]	154.9[c]	165.5[b]	157.9[a]
Mean daily gain (kg)	0.858[c]	0.899[a]	0.811[b]	0.894[a]
Feed : gain ratio	2.61	2.65	2.69	2.63
Carcass trait				
Dressing (%)	79.5[b]	79.0[a]	78.9[a]	78.5[a]
Backfat (mm)	12.88[b]	13.83[a]	13.21[ab]	13.89[a]
Lean meat yield (%)	54.3[b]	53.0[a]	53.4[ab]	52.5[a]
Loin eye area (cm^2)	42.9[c]	41.3[a]	45.6[b]	40.1[a]
Shoulder lean (%)	48.1[b]	47.9[b]	47.0[ab]	46.9[a]
Loin lean (%)	52.1[b]	50.5[a]	52.2[ab]	50.4[a]
Ham lean (%)	63.4[b]	61.1[a]	61.8[a]	60.8[a]
Loin marbling score	1.71[b]	1.78[b]	1.78[b]	2.92[a]
Loin fat (% of dry matter)	16.2[ab]	15.5[b]	16.9[ab]	18.2[a]
Loin protein (% of dry matter)	12.2[b]	12.2[b]	11.6[a]	11.9[ab]
Loin drip loss (%)	11.7[c]	12.1[c]	14.2[b]	10.2[a]
Ham drip loss (%)	9.5[d]	8.0[c]	14.1[b]	10.5[a]

Different letters following means indicate significant differences.

gain, while Hampshire pigs grew the slowest. Feed:gain ratio was lowest in Yorkshires and highest in Hampshires. Yorkshire pigs had the lowest backfat depth, although this was only about 1 mm less than in the fattest breeds, Durocs and Landrace.

Differences in carcass yield were small. Yorkshires (54.3%) were superior to Hampshires in lean meat yield (53.4%). Durocs had the lowest yield (52.5%). Yorkshires had the highest proportion of lean in the ham (63.4%), while Durocs had the lowest (60.8%). Yorkshires and Hampshires had the highest proportion of lean in the loin (52.1 and 52.2%, respectively).

Meat quality was estimated by drip loss and subjective scores for marbling, colour and structure. Assessments of meat quality were also obtained. Drip loss, an inverse measure of water-holding capacity, was highest for the Hampshire pigs. The high drip loss of Hampshire pigs suggests that the Napole gene was probably at high frequency in the Canadian Hampshire population. Duroc pigs consistently had the highest values for marbling score and colour and structure of the loin, while Landrace scored lowest for colour and structure of loin. However, the Landrace had the highest colour score for ham. Higher values for colour and structure indicated darker and firmer appearance of the meat from Durocs.

These results confirm that organic producers should choose breeding stock based on meat quality characteristics, as well as growth performance. Within-breed data were also analysed in this study, comparing data from the top and bottom breeds for each trait. It was assumed that the variation within each breed would be similar. As an example, the difference between the top and bottom breeds for days to 100 kg was 10.6 (Hampshire versus Landrace) while the difference between the top 10% and bottom 10% of herds was estimated to be slightly higher, 14 days. This indicated that there was more opportunity to improve days to 100 kg by selecting pigs from the best herds within a breed than by choosing between breeds. Similar analyses can be done by comparing the ratio of herd range to breed range. Where this ratio is greater than 1, the difference between herds within a breed is greater than the difference between the best and worst breed for that trait (Ball, 2000).

The review of de Vries *et al.* (2000) confirmed significant breed effects for intramuscular fat and muscle water-binding capacity, colour and tenderness. The meat of Pietrain and Belgian Landrace pigs is often of lower quality (pale, exudative and less tender) compared with the meat from Large White or French Landrace pigs. This breed effect appears to be completely explained by a high frequency of a single gene, the halothane gene, in affected animals. It is important, therefore, to ensure that animals in the breeding herd are free of this gene, to ensure high meat quality.

The Large White and Duroc breeds have been found to provide meat of high quality. Also the meat from Landrace can be of high quality, provided that the halothane gene has been eliminated. An extra benefit for the meat from Durocs is a reported higher content of intramuscular fat compared with Large White and Landrace pigs, which can positively contribute to eating quality. In one study (MLC, 1992) it was reported that as the percentage of Duroc genes increased from 0 to 75% the meat was scored by panellists as being more juicy, more tender and with higher pork flavour. The same study reported correspondingly higher haem pigment content, resulting in improved meat colour.

Wood and Cameron (1994) reported lower levels of marbling in loin meat from European breeds (0.5–2.0%) than from American breeds (2.0–5.0%). This finding favours the use of Duroc and Hampshire breeds.

Comparisons of meat quality between European and American breeds with Chinese pure-bred or cross-bred pigs were also reviewed by de Vries *et al.* (2000). They revealed that the Chinese breeds gave more tender, more juicy and tasty meat. However, the amount of visible fat was judged as excessive. Therefore there was no evidence of any beneficial effect of the Chinese Meishan breed on overall meat quality. Trials involving traditional European breeds were also reviewed. Meat from Corsican pigs was found to have a better water-binding capacity than that from Large Whites. Meat from Iberian pigs was found to have a lower level of ultimate muscle pH and lower contents of haem pigment and intramuscular fat than meat from Landrace pigs. British breeds (Tamworth, Gloucester Old Spots, Saddleback and others) had meat that was less pale and less watery than the meat from improved breeds such as Large White, Pietrain, Landrace, Hampshire and Duroc. The meat from Tamworths scored the highest overall acceptability.

Studies on intramuscular fat in relation to breed were also reviewed by de Vries *et al.* (2000). Analysis of meat quality data of F2 crosses between Meishan and Dutch pig strains indicated a recessive major gene for intramuscular fat, originating in the Meishan. Animals with two copies of the gene had an average of 3.9% intramuscular fat in the loin, whereas carriers and homozygous negative animals had 1.8%. This gene may be present in other breeds, allowing for improvement in the marbling level of pork.

Other reports confirm that a high content of intramuscular fat in certain heritage breeds results in higher pork quality. For instance, Rodrigues and Teixeira (2014) found that taste panellists rated pork from the Portuguese Black breed (Preto Alentejano) more highly in terms of juiciness, tenderness and flavour than pork from a commercial breed. The challenge for the organic producer is therefore how to achieve a higher intramuscular fat level without increasing the levels of the other fat deposits (subcutaneous, abdominal and intermuscular).

The content of intramuscular fat appears to be affected more by breed than by feed (Ngapo and Gariépy, 2008). These researchers also concluded, based on an extensive review of relevant findings, that while intramuscular fat content is regarded as having a beneficial effect on the eating quality of pork, some research indicates the reverse.

Wood *et al.* (2004) conducted a study on uncastrated male pigs to examine the effects of breed, diet and muscle on growth, carcass fatness, and on sensory traits and fatty acid composition of the meat. Four breeds were involved: two modern breeds, Duroc and Large White, and two traditional breeds, Berkshire and Tamworth. The pigs were reared from 9 weeks of age until slaughter after a 12-week period. They were fed one of two pelleted diets: a conventional diet (C) designed to promote fast lean growth in

Fig. 6.4. Some indigenous breeds are not as suitable for organic production because of poor body conformation.

modern pigs (200 g CP/kg, 11.4 g lysine/kg, 14 MJ DE/kg); and a low-protein (L) diet described as being designed for slower-growing pigs (160 g CP/kg, 6.8 g lysine/kg, 13 MJ DE/kg). The diets differed in energy:protein ratio, chosen to produce extremes of fatness of the animals and meat. The L diet had a higher ratio of energy to lysine. The ingredients of the two diets were the same, although in different proportions. The fat contents and the fatty acid compositions of the fats were similar. The diets were fed twice daily at a level estimated to be 90% of the *ad libitum* intake. The muscles investigated were the 'white' longissimus dorsi (LD) and the 'red' psoas major muscle (PS). It is known that muscles differ in the amount and fatty acid composition of the main lipid fractions, neutral lipid and phospholipid, these two constituting marbling fat. Variations in these explain some of the quality differences between muscles, for example in shelf-life and flavour. Steaks were cut from these muscles after slaughter, cooked on a griddle and subjected to sensory assessment by a trained taste panel of ten females. The panellists used 8-point category scales to score the intensities of pork odour and abnormal odour of fat (LD only) and tenderness, juiciness, pork flavour and abnormal flavour of lean. They also scored flavour liking and overall liking.

The results showed that both breed and diet influenced growth rate and carcass composition. The two traditional breeds, Berkshire and Tamworth, grew much more slowly than the two modern breeds, Duroc and Large White, and their carcasses contained much less lean and more fat (Table 6.5). Backfat thickness at the P2 position was also much higher in the two traditional breeds.

These results confirmed the effects of genetic selection over many years on the growth rate and carcass fat content of pigs. The effects of diet showed that reducing the proportion of protein relative to energy in the diet consistently increased fat deposition, supporting the approach taken in formulation in Chapter 5 diet to maintain the correct balance of energy to protein and AA.

Diet

An important observation of the Wood *et al.* (2004) study was that a lower-protein diet increased carcass fatness more in the two modern breeds than the two traditional

Table 6.5. Effect of breed and diet on growth and carcass quality of pigs (from Wood *et al*., 2004).

Measure	Diet[a]	Berkshire	Duroc	Large White	Tamworth
Daily gain (g)	C	425	659	658	435
	L	397	519	489	385
Backfat thickness at P2 (mm)	C	15.1	9.1	7.8	14.7
	L	15.9	9.4	8.2	15.1
Carcass fat (%)	C	32.1	13.0	12.0	25.9
	L	35.3	17.7	17.5	29.4
Tenderness, LD		4.16	3.96	4.35	3.93
Juiciness, LD		4.29	4.18	4.18	4.05
Flavour liking		4.19	3.89	3.91	4.15
Overall liking		3.71	3.47	3.60	3.60

LD, 'white' longissimus dorsi muscle.
[a]Diet C contained 200 g crude protein, 11.4 g lysine and 14 MJ digestible energy per kg; diet L contained 160 g crude protein, 6.8 g lysine and 13 MJ DE per kg.

breeds, a result similar to that reported earlier by Wood *et al*. (1979). Thus protein and energy levels in pig diets need to be adjusted in relation to genotype. Fast-growing genotypes such as the Large White, with a high capacity for muscle growth, can utilize diets high in protein and energy without becoming fat. When insufficient protein is provided in the diet, excess energy is diverted to fat deposition.

The inclusion of a third dietary treatment in the Wood *et al*. (2004) study would have been interesting, namely a diet similar to the L diet in protein content but with the same energy:protein ratio as in the C diet. The results obtained with this diet would have helped in establishing the appropriate dietary regime for traditional breeds to avoid excessive carcass fatness.

The two modern breeds in the Wood *et al*. (2004) study had higher scores for tenderness in the 'white' (LD) and the 'red' (PS) muscles than the traditional breeds, and the two traditional breeds scored better for flavour. The lower-protein diet produced fatter carcasses, especially in the two modern breeds, and in particular increased neutral lipid fatty acid concentrations in both muscles (intramuscular fat). This increased pork juiciness and tenderness but reduced pork flavour. PUFA concentrations in neutral lipid were higher in the animals with lean carcasses (i.e. Duroc and Large White breeds, and the C rather than the L diet). Phospholipid fatty acid composition was less influenced by breed and diet although Durocs had higher concentrations of the n−3 PUFA EPA and DHA in both muscles. An interesting finding was that marbling fat in LD and PS was high in Duroc and Berkshire and low in Large White and Tamworth, i.e. it did not follow the same pattern as carcass fat. High marbling fat was associated with higher tenderness and juiciness scores in LD but not PS, and especially in Duroc and Berkshire.

Pork flavour and flavour liking were found to be higher in the two traditional breeds and overall liking was higher in Berkshire for both muscles. The L diet resulted in fatter meat, particularly in intramuscular rather than subcutaneous fat. This diet produced more tender and juicy meat, although pork flavour and flavour liking were reduced. Breed affected the fatty acid composition of intramuscular neutral lipid, with high values for the saturated fatty acids, myristic and palmitic, in Berkshire and Tamworth (fat carcasses) and high values for PUFA in Duroc and Large White (lean carcasses). Durocs had particularly high concentrations of the long-chain PUFA EPA and DHA in phospholipid of both muscles. Diet influenced growth rate and fatness. Breed effects on sensory scores given by the trained taste panel to griddled LD and PS steaks were relatively small.

One question often asked by organic producers is whether carcass fatness is a good indicator of the amount of fat in the meat. The Wood *et al*. (2004) study examined this relationship and showed that it varied with breed. Durocs had high marbling fat at low P2 values and Tamworths had low marbling fat at high P2. As stated above, marbling fat in LD and PS was high in Duroc and Berkshire and low in Large White and Tamworth, i.e. it did not follow the same pattern as carcass fat.

This result has been reported by other researchers, posing somewhat of a dilemma for organic producers.

Organic pork has been shown to have a higher lipid and protein stability during storage than conventional pork (Karwowska and Dolatowski, 2013). This can be explained by the feeding method. The researchers found no differences in iron content of the meat or in myoglobin oxidation.

Zhao *et al*. (2016a) compared the mineral content of pork from organic and conventional farms. Conventional pigs were given a commercial feed with added minerals, while the organic pigs were given a feed based on organic feedstuffs. The content of macro-elements (Na, K, Mg and Ca) and some trace elements (Ni, Fe, Zn and Sr) in organic and conventional meat samples showed no significant differences ($P > 0.05$). Several trace element concentrations in organic pork were significantly higher ($P < 0.05$) compared to conventional pork: Cr (808 and 500 μg/kg in organic and conventional pork, respectively), Mn (695 and 473 μg/kg) and Cu (1.80 and 1.49 mg/kg). The results showed considerable differences in mineral content between samples from pigs reared under organic and conventional systems. Zhao *et al*. (2016a) made the interesting observation that mineral analysis might be used to authenticate organic pork. The same group Zhao *et al*. (2016b) investigated the carbon and nitrogen isotopic ratio in pork from organic and conventional systems. The average carbon and nitrogen isotope ratios for various organic tissues, including hair, blood and defatted meat, were higher than in the tissues of conventionally raised pigs. Discriminant analysis of the results based on a combination of carbon and nitrogen isotopic ratios in defatted meat gave a 100% correct classification of the two types of meat, suggesting another method of verifying the authenticity of organic pork.

Entire (Uncastrated) Males

An unresolved issue in organic pig production is whether male animals not destined for entry to the breeding herd should be castrated. The appropriate section in the Canadian Organic Regulations is as follows:

> Castration causes considerable pain and distress … but leaving males intact can increase the risks of fighting and of boar taint in meat. These risks are lowered if males are marketed at lower weights (well before sexual maturity), but intact males may need more space and special management to avoid aggression. If castrating, the procedure should be performed before piglets reach 2 weeks of age … Castration at older ages requires the use of anaesthetics and analgesia.
>
> In Canada hogs are usually marketed at 106–125 kg although the tendency is for increased size. Castration is demanded principally to avoid boar taint which occurs at about 90 kg or heavier. If pigs can be marketed at lower weights the benefits of not castrating include: up to 13% faster growth, more efficient feed conversion (can be 14% higher), and 20% leaner carcass. The Soil Association standards prohibit castration – average liveweight at slaughter in the UK is 98 kg (74 kg CW).

It is clear that while many organic producers would like to avoid the need to castrate these animals the economics of their production as meat animals indicates that uncastrated males are unsuitable as meat animals.

This conclusion is confirmed in a recent report from the Danish Centre for Food and Agriculture (Hansen, 2015). As pointed out in the report the reason for the reduced economy of production without castration is that too many uncastrated animals have to be discarded at slaughter due to boar taint. This is despite the boars having a better feed efficiency and leaner meat than castrates. The calculations showed that producing castrated finishing pigs with a final weight of 86 kg (barrows) gave a gross margin of 363 DKK per pig produced and 1216 DKK per allocated pen space per year. A production of pigs of equivalent weight at slaughter but not castrated gave a gross margin per pig of 187 DKK and 626 DKK per unit space. The markedly lower gross margin is because 20.9% of the non-castrated pigs had to be culled because of boar taint.

As explained in the report, two compounds are mainly responsible for the presence of boar taint in the cooked meat, skatole and androstenone. Some management procedures can be used to mitigate the problem. A research project NO CAST, which received funding from the Green Development and Demonstration Programme, showed that feeding boars dried chicory root or grain four days before slaughter could significantly reduce the concentration of skatole. Jensen and Hansen (2006) had shown previously that feeding fresh chicory roots for 2 months prior to slaughter decreased significantly the concentrations of these malodorous compounds in the meat.

Experiments have also shown that the slaughter of boars at a lower weight can reduce the concentration of the hormone androstenone. It is also known that keeping the entire males as clean as possible from manure can help, although none of these procedures prevent the problem entirely. As found by the Danish researchers, feeding the pigs either chicory or grain in the diet in last few days before slaughter at a lower weight (61 kg) was beneficial. Feeding grain to the pigs reduced the cull to 12.2% and feeding chicory reduced the cull to 8.6%. However this was not sufficient to achieve the same returns as from the production of organic castrates.

The castrates had a lower feed efficiency and thus higher feeding costs and a poorer lean meat percentage than non-castrated pigs, but since 99% of the castrates passed the boar taint test, this production system gave the best returns to the farmer.

Consumer Attitudes to Organic Production

Organic production is largely consumer-driven, therefore it is important to take into account consumer attitudes in selecting the appropriate breeds and strains for organic pig production.

One of the most striking consumer trends in recent years has been the increasing demand for natural and healthy foods where also ethical issues (such as animal welfare and health) are taken into consideration (Andersen *et al.*, 2005). Safety has also become a very important issue of consumer concern in modern food production, prompted mainly by several health crises (hormones, bovine spongiform encephalopathy, antibiotics, dioxin contamination of feed, etc.).

The purchase of pork meat by the consumer is therefore governed by two main factors: (i) the perceived quality based on appearance, price, presentation and labelling, and ethical and philosophical considerations such as freedom from chemical residues, etc.; and (ii) the actual quality experienced after cooking and eating. European research indicates that the first factor is much more important than the second (Scholderer *et al.*, 2004). Consumers expect a substantially higher quality in pork produced in organic and free-range systems.

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7

Integrating Feeding Programmes into Organic Production Systems

The main differences between organic and conventional pig production relate to housing system, genotype, range of feedstuffs available for dietary use and disease prevention measures. These differences need to be recognized in devising appropriate feeding programmes for organic pig units.

Housing System

Organic production requires that the animals be provided with outdoor access. Outdoor production is often perceived as being a more sustainable, traditional and family-based farming system. It is also often perceived to be more environmentally friendly, generating less smell and pollution than slurry-based intensive units. Thus organic products have more appeal for the consumer.

Edwards (2005) described the various outdoor pig production systems in Europe, conventional and organic. In conventional units the animals are typically housed indoors after weaning, sometimes in buildings with outdoor runs and more often in fully enclosed buildings. The finishing pigs in conventional production are almost always housed, either in deep-litter systems or in conventional controlled-environment housing. In contrast, the farms producing organic pigs must follow EU standards and any additional requirements imposed by local certifying agencies. The EU standards require that breeding animals have access to pasture. In some certification schemes it is also a requirement that finishing pigs be kept at pasture. Another major European outdoor system is the traditional Mediterranean silvopastoral system. This system uses indigenous breeds that are extensively pastured in natural forests for the production of high-value dry-cured hams. Typically, all phases of production take place outdoors, sometimes in extreme conditions in mountain zones. These animals reach their slaughter weight at an advanced age, conferring preferred attributes to the meat. In addition, finishing takes place during autumn in forests of oak or chestnut and the animals convert large quantities of acorns or chestnuts into fat deposits. There is thus no standard outdoor system for pig production in Europe. A similar situation prevails in other regions.

An outdoor system based on the 'Roadnight' system employing movable arks (nicknamed 'pigloos') that gave good results in the rigorous climate of north-east Scotland was described by Blair and Reid (1965). These authors found that the system was, on a per sow basis, at least as efficient as a conventional system of rearing. Some figures indicating the physical and economic efficiency of the two systems are given in Table 7.1.

In this system groups of sows were batch-farrowed twice yearly during March and September in small individual wooden arks on pasture, spaced at 6–8 per hectare.

Table 7.1. Efficiency of weaner production by the Roadnight and a conventional pig-rearing system in Aberdeenshire, Scotland (from Blair and Reid, 1965).

	Roadnight	Conventional
Number of farms	9	9
Average amount of feed		
meal (tonnes per sow per year)	1.15	1.30
Skimmed milk (litres per sow per year)	0	414.1
Labour		
Mean (hours per sow per year)	18.2	35.8
Average number of veterinary calls (per 10 sows per year)	0.9	8.2
Weaners produced		
Average number of litters (per sow per year)	2.0	1.9
Average number of piglets weaned (per sow per year)	17.4	16.7
Average piglet weight at 8 weeks (kg)	20.1	17.5

The piglets remained with their dams up to the age of 8 weeks when they were disposed of as weaners or were transferred to finishing yards. At this time the sows were dried off, re-mated and housed outside in larger communal arks until the next farrowing. Generally only crossbred sows were used for the system, usually between Wessex Saddleback and Large White or Landrace. This cross was believed to combine the traditional hardiness and mothering ability of the Wessex Saddleback with the better carcass characteristics of the latter breeds. The sow feed was generally a purchased feed in either cube or nut form, which was considered more suitable than a meal for feeding to stock on pasture. Creep-feed was generally in pellet form and given to the young pigs from the age of 2–3 weeks in covered feeders. Drinking water was supplied to each ark from a central point by the use of alkathene tubing, which had the advantage that the water system rarely froze. Weaner production by the outdoor system was at least as efficient as production by a conventional system. Sows on the Roadnight system produced on average two litters of heavier piglets per year. No information was available on the carcass quality of the weaners produced on this system since they were marketed to other

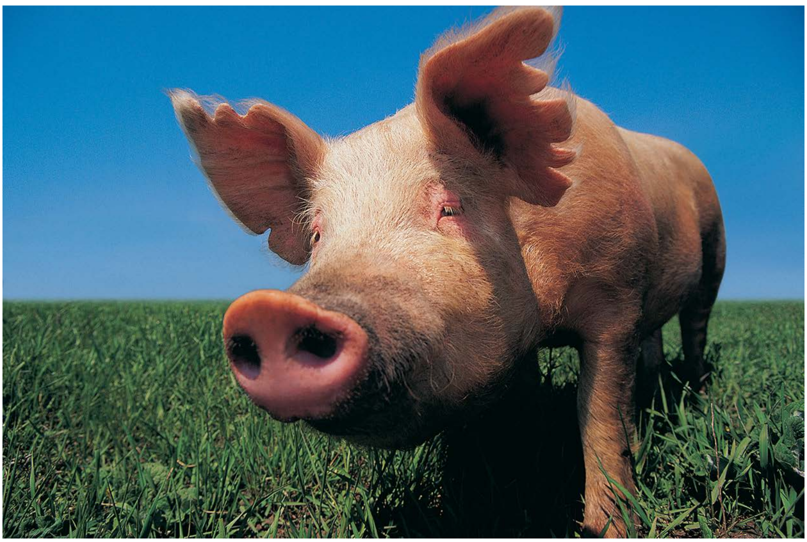

Fig. 7.1. Pig enjoying the organic lifestyle on a sunny pasture.

farmers for finishing. The slightly lower number of weaners produced on the conventional system may be attributed to a common difficulty in getting sows to conceive in the late autumn in the north-east of Scotland, especially when housed conventionally. Total feed costs were slightly lower on the Roadnight system. Although the amount of feed used was considerably less than on the conventional system (due probably to the provision of pasture), the increased cost of purchased feed reduced the potential savings on the Roadnight system. Savings in the costs of feed for this type of operation could be obtained by group trading and access to a mill for cubing, and by the use of home-grown grain in the diets. Housing costs were lower with the outdoor system. An important finding was that the amount of veterinary attention needed for these herds was much less with the outdoor system. The Roadnight system did demonstrate one disadvantage of outdoor systems in colder climates, namely the concentration of weaners at two periods in the year.

Other studies show that, provided the necessary changes are made to the feeding regime, the performance of herds with outdoor management can come close to that of herds housed conventionally. This was demonstrated in the results of a survey conducted by BPEX (2008) in the UK (Table 7.2).

These results indicated that outdoor management gave slightly better health, as shown by the mortality and replacement rates. However, the number of pigs weaned per sow per year and litter size were slightly lower with outdoor management, confirming the results of other studies. This was not due to conception rate, which was slightly better with outdoor management. Farrowing problems were also slightly reduced with outdoor management.

Table 7.2. Performance of breeding herds with outdoor management or housed in conventional indoor facilities in the UK (from BPEX, 2008).

Measure	Outdoor	Indoor
Sow mortality (%)	3.1	3.9
Replacement rate (%)	45.8	47.7
Conception rate (%)	82.2	81.6
Litters per sow per year	2.19	2.25
Liveborn piglets per litter	10.9	11.4
Mortality of piglets born alive (%)	12.3	13.0
Pigs weaned per sow per year	20.9	22.4

The UK average for outdoor herds is around 22 pigs weaned per sow per year, indicating a target for the organic producer.

These results of the BPEX survey suggest that producers using outdoor management (including organic producers) need more advice on how to increase sow productivity.

The report also indicated a high sow replacement rate.

Sows produce larger litters than gilts so keeping the number of gilt replacements to a minimum will improve production efficiency. Most commercial producers replace 30–40% of their herd each year. Therefore, the nutrition and management of gilts is an important consideration in optimising reproductive efficiency in organic production.

The long lactation period (6–8 weeks) in organic production is another factor that needs to be taken into account since it can result in the sow losing condition and taking longer to re-breed.

Effect of climatic environment on nutritional requirements

Energy requirements of outdoor pigs are generally higher because of increased exercise and exposure to outside temperatures, but protein requirements are relatively unaffected (Close and Poornan, 1993; Edwards, 2003). Conversely, at high ambient temperatures, voluntary feed intake may be reduced to a level that is inadequate to meet requirements for high production (Edwards, 2005). Therefore, in situations of low and high ambient temperatures, changes may have to be made to the diet, otherwise both animal welfare and productivity may suffer. The available data on this subject are limited (Edwards, 2005). Some investigations indicate that growth rates obtained in an outdoor system can be comparable to those obtained in indoor production (Lee *et al.*, 1995; Andresen *et al.*, 2001; Gustafson and Stern, 2003). However, variable feed conversion rates have been obtained. In the summer, a feed conversion comparable to indoor conditions has been obtained in some investigations (Sather *et al.*, 1997) whereas in other investigations a lower efficiency of feed conversion was reported for other periods of the year (Sather *et al.*, 1997; Stern and Andresen, 2002). Pigs reared outdoors and fed *ad libitum* had a slightly lower growth rate and a considerably lower efficiency of feed conversion than pigs fed *ad libitum* and reared indoors (Strudsholm and Hermansen, 2005). This was probably due to a higher energy requirement for thermoregulation and activity in the outdoor housed pigs. Studies carried out in the summer period showed a higher growth rate for outdoor-reared than for indoor-reared pigs (Gentry *et al.*, 2002). However, the differences in growth rate reported were small.

Most organic producers, at least in the temperate regions, do not make changes in the composition of the diet to account for winter temperatures. During cold weather animals fed *ad libitum* simply eat more (around 10–15%) to maintain body processes and animals fed restricted amounts of feed have to receive a higher feed allowance. The ideal environmental temperature for a growing pig is around 21°C and for a finishing pig is slightly lower, about 16°C. If the temperature falls below the ideal it is advisable to increase the amount of bedding in the sleeping area as a way of helping to keep the animals warm. Producers accept higher feed intakes and lower efficiencies of feed utilization during cold periods. It is logical also to increase the allowance of forage at this time. The increased intake of fibre results in an increased heat of fermentation in the gut, which helps to keep the animals warm. However, as overall efficiency of organic production becomes more important, producers may have to alter the composition of dietary mixtures for animals with access to outdoors during periods of cold weather. It would be logical to reduce the concentration of protein and AA to take into account the increased intake of feed, to maintain the target intake of nutrients on a daily basis. For instance, if intake increased by 10% then the concentration of protein and AA could be reduced by about 10%. Another approach could be to raise the energy level of the diet in relation to protein and other nutrients, perhaps by the use of fat, in such a way as to result in the same intake of AA but an increased intake of energy. Such changes should be made following advice from a nutritionist. Few organic producers are in a position to make these changes, although those using purchased feed could do so in collaboration with a feed manufacturer. During these periods of cold weather it is advisable that the animals should be provided with ample, dry bedding in the sleeping area.

Periods of high heat/high humidity can be expected to result in the opposite effect, a decrease in voluntary feed intake, leading to slower growth and a lower efficiency of feed conversion. For instance, Trezona *et al.* (2002) in an Australian study housed pigs within their thermoneutral zone (the ambient temperature range over which there is no change in metabolism to keep the animal warm or to cool; approximately 20–26°C for pigs) for 24 hours per day, or housed them at 32°C for 20 hours and then within the thermoneutral zone for the remaining 4 hours per day. All animals were fed the same diet *ad libitum*, from an initial weight of 20 kg to slaughter weight at 102 kg. Voluntary feed intake (kg/day), average daily gain (g/day) and kg feed/kg gain were, respectively, 2.75 and 2.17; 802 and 758; and 3.43 and 2.86. A study in France demonstrated the adverse effects of high environmental temperature on milk production in lactating sows and on growth of the piglets (Renaudeau and Noblet, 2001). In this study the sows (Large White × Landrace) were housed at constant environmental temperature, 20 or 29°C, over a 28-day lactation period. Although nursing frequency was increased at the higher temperature (39 versus 34 sucklings per day) milk production decreased from 10.43 to 7.35 kg/day, and over the lactation period piglet growth rate decreased from 272 to 203 g/day and weaning weight decreased from 9.51 to 7.52 kg. Providing creep-feed from 21 days onwards helped to offset the effects of reduced milk production, intake of creep-feed per day during the fourth week being 388 g per litter at the higher temperature versus 232 per litter at the lower temperature. These results indicate the importance of providing creep-feed to litters of sows housed under hot conditions, and of supplying the creep-feed as early as possible. Boars are also affected by high ambient temperatures, resulting in lethargy, disinclination to breed and reduced fertility.

In these situations it is advisable to consider altering the feed formulation to a higher nutrient density designed to ensure the correct intake of nutrients in a lower total intake. Some producers add fat to the diet as a way of increasing the energy content. Another way to address this issue would be to adopt a formulation similar to the summer formulations advised by the University of Minnesota shown in Chapter 5. In addition the diet should be formulated, if possible, during periods of hot weather to minimize the inclusion of less-well digested feedstuffs including forage, to avoid raising the body temperature by the increased heat of fermentation of fibre. Strategies such as the provision of cooled drinking water and feeding during the cooler parts of the day should be adopted to try and encourage intake of feed during periods of hot weather. The provision of a wallowing area is important, also shade. Producers can check if the animals are heat-stressed by carrying out checks for rectal temperature (normally 39°C in mature animals) and respiration rate (normally 13–18 breaths per minute). Values higher than these are indicative of heat stress.

Genotype

This aspect is dealt with in some detail in Chapter 6. Animals kept outdoors need to be robust, to withstand the rigours of climate (either heat or cold) and compete for feed and shelter. In organic systems, emphasis is placed on using traditional breeds adapted to the local conditions and extensive production systems.

Fig. 7.2. A good outdoor area for pigs with a pool for wallowing. (Courtesy of Basil Bactawar.)

Diet Composition and Feeding Level

It is pertinent to consider what changes should be made to the composition and feeding level of the feed mixture in relation to the need to provide access to outdoors and pasture.

Forages have a long history of use in pig production and in the past forage was considered a vital component of the feed as it provided nutrients and unidentified growth factors. However, the discovery of vitamins and the widespread adoption of successful indoor systems of production have led to a scarcity of up-to-date knowledge on the value of forage for application in organic pig production. Few data have been published on the nutritional value of forage for pigs, and the available data relate mainly to processed lucerne meal. Roughage intake can be beneficial to pig welfare, with bulky diets promoting satiety when feed intake is limited (Edwards, 2005). They may also influence health beneficially, through both the promotion of a desirable gut microflora profile and a reduced incidence of gastric ulceration (Lee and Close, 1987). However, do pigs derive a substantial amount of nutrients from this source, enough to require that the dietary composition be altered? The forage (or roughage) may be in the form of grazed vegetation or supplementary feed silage or root crops.

The extent to which pasture and roughage can contribute to the nutritional needs of the animals will depend on voluntary feed intake and ability to utilize the fibrous components. Adult sows have a more developed intestinal system than younger pigs and are better able to digest fibrous diets. If high-quality pasture is available, gestating sows are able to obtain 30–45% of daily energy intake from this source (Rivera Ferre *et al.*, 2000). However, lactating sows fed whole-crop silage *ad libitum* are only partly able to compensate for lower levels of concentrate (Kongsted *et al.*, 2000). Forage is likely to be utilized to a limited extent in growing pigs. Studies have shown that protein digestibility of various fibre-rich diets for growing pigs is less than 45% (Carlson *et al.*, 1999).

Results of a study in Denmark suggest that forage provides a low amount of nutrients for growing-finishing pigs (Strudsholm and Hermansen, 2005). The pigs were crossbred (Danish Large White × Danish Landrace sows mated to Danish Duroc boars), produced organically. From weaning they were reared on pasture with free or limited access to a regular diet until they reached slaughter weight. The restricted-fed animals received approximately 80% of *ad libitum* intake. The experiment took place from January 2002 to April 2003, during which time the average maximum temperature was 10.9°C (24 h) and the average minimum temperature was 4.4°C. The diet consisted of (g/kg) 253 wheat, 220 barley, 160 yellow peas, 144 rapeseed cake, 100 sweet lupin, 100 full-fat soybeans, and 23 mineral and vitamin mixture. It supplied 13.8 MJ ME, 192 g protein and 10.5 g lysine per kg. In addition to the diet, the pigs had *ad libitum* access to clover grass silage or, in the summer period, fresh clover grass in the pens. The results showed that the animals were not able to compensate for a 20% reduction in feed intake by an increase in herbage intake of 18%. Compared with outdoor pigs fed *ad libitum*, restricted feeding resulted in a significantly lower daily gain (107g) and a lower feed consumption (6.3 MJ ME/kg gain). As a result the restricted animals took an average of 17 more days to reach market weight (177 versus 160 days of age).

Another finding in the trial conducted by Strudsholm and Hermansen (2005) was that the carcasses were leaner (61.9 versus 59.8%) and average backfat was less (14.7 versus 16.5 mm) in the restricted animals compared with the animals fed *ad libitum*, the effects being similar to those typically reported in restricted animals and not provided with access to pasture.

To date the Danish allowances for vitamins and minerals in pig diets do not take into account the natural content of the feed ingredients. However, some results indicate that this policy may change at some time in the future. Preliminary studies on gestating sows in that country showed that organically reared sows not receiving supplementary vitamins and minerals had higher blood concentrations of iron, zinc, vitamins A and D and β-carotene and at least similar concentrations of other vitamins and minerals as sows from a herd fed conventional diets (Christensen-Jakobsen and Sagredos, 1990). Organic pigs reared outdoors without a dietary supply of vitamins and minerals had a similar gain in weight as those supplied with vitamins and minerals. On the basis of these findings Jakobsen and Hermansen (2001) concluded that that the vitamins and minerals in the feed and soil, and synthesis from sunlight, can be utilized to a higher degree than normally believed.

Several studies have investigated the effects of omission of vitamin and mineral supplementation from pig diets and the results lend some support to that conclusion. Edmonds and Arentson (2001) fed conventionally housed finishing pigs on diets devoid of supplemental vitamins and trace minerals and reported no effects on growth performance, except in pigs housed under more stressful conditions. Overall there were no treatment differences for average daily gain, average daily feed intake, average gain:feed ratio, longissimus muscle area or backfat measured at the last rib. However, omission of vitamin and trace mineral supplementation resulted in markedly reduced content of vitamin E in longissimus dorsi and ham muscles and of copper concentration in ham muscle. Mavromichalis *et al.* (1999) reported minimal effects on finishing pig performance, carcass traits or muscle quality following omission of vitamin and trace mineral supplementation for periods from 28 to 30 days. Earlier work by Patience and Gillis (1995, 1996) also revealed no significant differences in performance or carcass traits from either 17 or 35–36 days of withdrawal of vitamin and trace mineral supplementation prior to slaughter. The riboflavin level in pork muscle, however, was reduced when supplemental vitamins were deleted from the finishing diet (Patience and Gillis, 1996). Research by Kim *et al.* (1997) revealed no significant effect from a 45-day withdrawal of vitamin and trace mineral supplementation on finishing pig performance or meat quality factors, such as colour, firmness and marbling. In contrast, Spurlock *et al.* (1998) reported a significant reduction in growth performance and feed intake as a result of withdrawing vitamin and trace mineral supplementation for a period of 44 days.

Another approach to the question of the adequacy of nutrient intake from forage is to estimate intakes based on dried forage. Rivera Ferre *et al.* (2001) estimated that sows are capable of ingesting around 1.2 kg of herbage DM per day. Using that figure and the nutrient details for grass meal set out in Table 4.18 the following comparison can be made (Table 7.3).

This comparison shows that good-quality herbage has the potential to supply a significant proportion of the nutrient needs of dry sows. However, given the present state of knowledge of the subject it is inadvisable to rely on herbage consistently as a major source of micronutrients. The quality of herbage is known to vary widely and pigs are known to consume relatively low amounts of herbage when they have access to normal rations. More research is needed on this topic before a clear conclusion can be drawn.

Therefore, it seems premature to recommend changes to the composition of the vitamin and trace mineral supplements fed to sows or growing-finishing diets of pigs allowed access to herbage. Should there be evidence that the forage being fed to the sows supplies a significant level of protein, then the protein level of the dietary mixture could be reduced. A similar approach can be taken to the question of energy provided by forage. Sow condition should be monitored and the ration of regular feed be adjusted to maintain the desired body condition score. Advice on this issue should be sought from a nutritionist. In addition it seems advisable that the regular diet of growing-finishing pigs be provided *ad libitum* regardless of the quantity of herbage provided. Further evidence from scientific studies on this issue may allow that recommendation to be revised. However, the recommendation for growing-finishing pigs is in keeping with established information on the digestibility of forage, namely that digestibility is relatively low in young pigs.

Producers with access to high-quality forage and a pasture situation could perhaps experiment by reducing the vitamin

Table 7.3. Comparison of estimated intake of nutrients from grass and daily nutrient requirements of gestating sows (from Rivera Ferre *et al.*, 2001).

Nutrient	Daily requirement	Provided by grass (dry matter basis) 1 kg	1.2 kg
Digestible energy (kcal)	6,265	2,332	2,799
Crude protein (g)	236	198.5	238
Lysine (g)	10.5	7.70	9.29
Methionine + cystine (g)	7.0	5.45	6.54
Threonine (g)	8.3	6.76	8.11
Tryptophan (g)	2.0	3.38	4.06
Calcium (g)	13.9	6.87	8.24
Phosphorus (g)	11.1	3.79	4.55
Chloride (g)	2.2	8.72	10.46
Magnesium (g)	0.7	1.70	2.28
Potassium (g)	3.7	27.37	32.85
Sodium (g)	2.8	3.10	3.72
Copper (mg)	9.3	7.30	8.77
Iron (mg)	148	NA	NA
Manganese (mg)	37	57.80	69.36
Selenium (mg)	0.3	0.05	0.07
Zinc (mg)	93	20.72	24.86
Vitamin A (IU)	7,400	10,424	12,509
Vitamin E (IU)	81	164	196
Biotin (mg)	0.4	0.24	0.29
Choline (mg)	2,300	1,603	1,924
Folacin (mg)	2.4	NA	NA
Niacin (mg)	19.0	80.70	96.84
Pantothenic acid (mg)	22	16.79	20.15
Pyridoxine (mg)	1.9	12.76	15.31
Riboflavin (mg)	6.9	16.90	20.28
Thiamin (mg)	1.9	13.74	16.49
Cobalamin (vitamin B_{12}) (μg)	28	0	0

NA, no data available.

and trace mineral premixes by 10–25%. Close monitoring of the herd by a veterinarian would indicate whether the reduction could be maintained or cancelled. The integrity of the welfare of the animals has to be maintained even if, at times, the intake of micronutrients is in excess of requirements.

Few nutritionists would agree that supplementary vitamins and minerals can be dispensed with entirely. Kienzle *et al.* (1993) reported sudden deaths, skin diseases, diarrhoea, increased restlessness and cannibalism in organic pigs. The diet used in this field study was described as consisting of cereals (barley, wheat, rye), field beans, limestone and deteriorated, raw potatoes without addition of a mineral mixture. Deficiencies of sodium, zinc and selenium were found in the diet and in animal tissues. The vitamin E status of the pigs was also below normal. In a study of 22 organic farms in northern Germany, Thielen and Kienzle (1994) found that the dietary CP and EAA levels were below requirements, especially during the initial finishing period. There were also serious imbalances in mineral supply, mostly because some farmers did not add mineral supplements for ideological reasons. As a result, growth performance was poor. Clinically apparent deficiencies, however, were not observed. The hygienic quality of the feedstuff was described as being often objectionable. It is surprising that such diets should have been in use on the farms involved in this investigation, calling into question the adequacy of the local certification standards.

The above findings indicate a need for the study of vitamin and mineral requirements and supply under organic farming conditions and for certifying agencies to ensure that adequate diets are used and that the welfare of the stock is not compromised.

Forage-based feeding systems

Use of forages can lower costs of grain and protein supplementation and producers with access to forage of proven quality may wish to follow the recommendations of the Purdue University Cooperative Extension Service (Kephart *et al.*, 1990) in utilizing forage in pig diets. According to these authors, studies have shown that pigs absorb more nutrients from forages after an adaptation period of at least 2 months, with nearly all of the fibre digestion taking place in the large intestine. Forages at an early stage of growth generally contain more protein than grains; therefore both grains and protein supplements may be reduced when using forages. However the digestibility of protein in forages is lower than in soybean meal or other protein supplements, a factor that needs to be taken into account in formulating appropriate dietary regimens. The authors also point out that forage feeding can simplify feeding and management of the breeding herd and improve the welfare of the animals. With the proper amount of forage in a complete feed, sows can be self-fed during gestation without adversely affecting weight gain or reproductive performance (although some feed wastage may occur). Sows are reported to be more content when the diet contains a significant amount of forage, compared with restricted-fed sows that receive only about 2 kg feed each day. Other advantages of forage feeding are that increased fibre in the diet prevents constipation during late gestation and early lactation. In addition, starter diets containing increased fibre levels have been shown to reduce diarrhoea problems, and pigs and sows on pasture may have fewer health problems because of improved sanitation and air quality.

These authors also point out the disadvantages of using forage in pig feeding. Fresh forages are low in DM, resulting in the pig having to consume more material to obtain the same amount of nutrients found in grain or in complete feed. Accordingly pastures and high levels of forage in the diet are less practical for pigs weighing less than 20 kg and for lactating sows. Another drawback to using forages, especially pastures, is that they might not be available during the entire year. Also, the pastures have to be rotated to prevent heavy bacterial and parasite contamination. The authors further advise that the feeding value of pastures is often overestimated by producers since forages may be heavily damaged by the pigs. Both the pasture and the forage crop must be well-managed to provide optimal feed savings. Producers may find this difficult especially during the spring and autumn months when damage from rooting the soil reaches a peak. Finally, pigs housed in a pasture setting have a higher energy requirement since they exercise more than those housed in pens indoors. Consequently sows require more feed during gestation, and market pigs may gain more slowly and less efficiently.

This extension bulletin contains details of the average nutrient composition of forage crops, showing that lucerne, maize silage, Kentucky bluegrass, legumes and growing rape are among the best sources of forage energy for pigs, and that legumes and growing rape and wheat crops are among the best sources of forage protein. The authors advise that the tabulated values be used as a guide in diet formulation, and that forage analysis should form the basis for diet formulation whenever practical. Analysis of CP, calcium and phosphorus was advised, also NDF and ADF to provide an estimate of the content of indigestible components. The cell wall fraction (NDF) contains all of the fibre, which is the least digestible component of the forage and consists primarily of cellulose, hemicellulose and lignin. None of the lignin is digestible and only 30–40% of the hemicellulose and cellulose is digestible. The content of cellulose in the forage can be estimated by subtracting ADF from NDF. The lignin can be estimated if ADF can be analysed further to give acid detergent lignin (ADL). The hemicellulose content can

Fig. 7.3. Forage is part of the diet of organic pigs. (http://media.istockphoto.com/photos/young-outdoor-raised-pigs-picture-id518177510)

be calculated by subtracting ADL from ADF. The authors advise that if levels of hemicellulose and lignin are found to be significantly higher than the average values quoted in the extension bulletin, then ME and CP concentrations in the forage will likely be lower than those shown.

Types of forage crops

Information and practical advice on the value of various forage crops was provided by Kephart *et al.* (1990) in this bulletin and is summarized as follows. The information will be most applicable to producers in North America but is of value to producers in other regions.

Legumes

Lucerne (alfalfa). Most of the research on the use of forage in pig diets has been with this crop. It appears to be the most practical forage crop for the pig because it can be used for both pasture and silage. Potential benefits to feeding lucerne during gestation include improved survival of the baby pigs during the nursing period and a reduced culling rate in the sow herd. Gestation diets containing approximately 600 g lucerne/kg can be self-fed. Growing pigs show satisfactory performance on diets containing lucerne, provided the level does not exceed 200 g/kg diet.

Alsike clover (IFN 2-01-314). This clover provides a leafy crop with fine stems, and it grows well in soils that are too acidic or too wet for red clover. It is less desirable where hot, dry summer conditions are common. It is often used in pasture mixtures.

Birdsfoot trefoil (IFN 2-20-786). Birdsfoot trefoil is palatable and similar in nutrient content to lucerne. Unlike lucerne, it grows well on poorly drained soils. While not as productive as lucerne on good soils, yields have exceeded yields of lucerne on wetter soils. Most varieties grow better in cooler climates.

Crimson clover (IFN 2-20-890). Crimson clover provides a good spring forage and sometimes winter forage in warmer climates.

Ladino clover (IFN 2-01-380). Ladino clover is a large-type white clover. Under optimum conditions, ladino clover will not produce as much forage per hectare as lucerne but the protein content is superior to that of lucerne.

Red clover (IFN 2-01-428). Red clover is a short-lived, relatively easy-to-establish perennial legume that will grow on soils too acidic or too wet for lucerne. Red clover is not as drought-resistant as lucerne. It is useful for pasture or silage. Several studies have shown that pigs on red clover forage grow as rapidly as those on lucerne.

Brassicas

Rape (IFN 2-03-865). Rape can be grown as a high-yielding, fast-growing annual forage crop and provides an excellent pasture for pigs over a long-growing season. The authors report that the feeding of rape can lead to photosensitization when grazed wet, white-skinned pigs being most sensitive.

Grasses

Bluegrass (IFN 2-00-777). Bluegrass may serve as a permanent pasture for pigs. The pasture can be grazed early, but it contains less protein than legumes and is usually dormant during the warmest part of the summer.

Smooth bromegrass (IFN 2-00-892). Bromegrass is a palatable crop that withstands heavy grazing. Its early spring growth enables it to be pastured for longer periods than many legumes. Studies show that pigs on bromegrass pastures require more grain and supplement than pigs grazing lucerne. Bromegrass can be successfully mixed with legumes.

Orchardgrass (IFN 2-03-439). Orchardgrass is a hardy perennial species that can tolerate trampling. It quickly loses its palatability if not grazed down to prevent the grass from becoming tall and mature.

Sudangrass (IFN 5-04-374). Sudangrass (sorghum) is an annual grass that is palatable to pigs and, when seeded thickly, provides ample forage during the hottest part of the summer when other species are dormant. The authors caution that the early growth of sudangrass contains a cyanogen, which may be converted to prussic acid (extremely toxic to pigs) under certain conditions such as wilting, trampling, chewing, frost and drought. Ruminants are more sensitive to cyanogens than are pigs. Poisoning can be avoided by delaying grazing until the grass reaches a height of at least 18–24 in (46–61 cm). Because sudangrass is low in protein, it is better adapted for sows and older market pigs.

Timothy (IFN 2-04-903). Timothy withstands heavy use, but it should only be included as a minor part of a pasture mixture since it is less desirable than most other pasture crops.

Winter rye (IFN 2-04-013). Winter rye seeded during late summer will provide a useful forage crop for winter or early spring grazing. Optimal planting time should provide just enough growth so that seed stems are starting to shoot when the plant enters winter dormancy.

Winter wheat (IFN 2-05-176). This cereal grain crop is at least as palatable and nutritious as rye, but does not yield as well and cannot be grazed as heavily.

Suggested dietary mixtures for use with pasture-fed animals are included in the bulletin and examples are set out in Tables 7.4–7.8. The mixtures have been formulated to take into account the contributions to the diet of energy and protein in the forage.

Methods of feeding forage

The bulletin (Kephart *et al.*, 1990) provides the following advice:

Pasture

Pastures containing a high percentage of legumes are generally the most practical for pig producers. On a DM basis, legumes are similar in energy content and higher in CP than grasses. Some grass species in the mixture may help to prevent soil erosion. A sample pasture mix might consist of seedings for permanent, rotational or annual pastures. The permanent pasture might contain seedings of bluegrass, white clover, orchardgrass and lucerne. The rotational pasture may include lucerne, red clover, ladino clover, sweet clover, alsike clover, orchardgrass, bromegrass and timothy grass. An annual or temporary pasture could be made up of brassicas, rape, soybeans, cowpeas, faba beans, sudangrass, rye, oats, wheat, barley, field peas, and mixtures of grass and legumes.

Optimum stocking rates depend on soil types, plant species and climate conditions. The authors advise that a stocking rate of about 10–15 gestating sows per hectare (double if irrigated) or about 25–30 growing pigs (double if irrigated) will make good use of the pasture crop without excessive damage. Sows should be fed approximately 1–1.5 kg of an appropriate dietary mixture daily while on pasture. Grower-finisher pigs should have free access to the dietary mixture at the same time they are grazing a pasture crop, using the formulations outlined in the tables above. The pastures should be ploughed, disced and reseeded at least every other year. This serves to level the pasture, re-establish plant growth and reduce bacterial and parasite contamination. When grazing pigs on legume pastures in northern latitudes the authors advise that at least 6 in (15 cm) of growth be allowed in the autumn before the arrival of a killing frost. This helps to reduce winter-kill by enabling the plant to build up root reserves.

Silage and haylage

Feeding programmes for gestating sows or replacement gilts weighing more than 110 kg can include silage and haylage. These forages should be chopped finely to prevent sorting by sows. It is also necessary to ensure that any ensiled forage is fresh and free of mould, to avoid reproductive problems. Maize silage can be offered free-choice. Intake is stated as being variable, about 4.5–5.5 kg per head per day. Sows should also be fed approximately 1.25 kg of a dietary mixture (Table 7.7) in addition to the silage. For best results the maize silage should be made when the ears have formed, and the plant is still green and not frosted. Silage made from maize nearing maturity is less palatable. Legume haylage can be offered *ad libitum*, with intakes around 2.5–3.5 kg per head per day, plus 1.25 kg of an appropriate dietary mixture (Table 7.5).

Table 7.4. Suggested dietary mixtures to supplement pasture for gestating sows (from Kephart *et al.*, 1990).

	Type of pasture		
	Legume	Grass	Legume–grass mix
Ingredient (kg/t)			
Maize	872	667.5	747.5
Soybean meal (44%)	93	281	199
Ground limestone	8	12	
Monosodium phosphate	23		
Dicalcium phosphate		31.5	29.5
Salt (NaCl)	6	6	6
Vitamin premix	3	3	3
Trace mineral premix	3	3	3
Calculated analysis			
Metabolizable energy (kcal/kg)	3282	3188	3172
Metabolizable energy (MJ/kg)	13.73	13.34	13.27
Crude protein (g/kg)	115.0	180.0	151.0
Lysine (g/kg)	4.9	9.9	7.7
Calcium (g/kg)	0.5	11.6	12.3
Phosphorus (g/kg)	8.1	9.5	8.8

The above mixtures assume that the sows will consume 1.6 kg pasture dry matter and 1.15 kg dietary mixture per day; and that pasture and feed together will provide a minimum of 340 g protein, 17 g lysine, 18 g calcium and 14 g phosphorus per day. The diets containing legumes are supplemented with monosodium phosphate as a way of providing phosphorus without adding calcium. The vitamin and trace mineral premixes suggested are designed for conventional production and are not directly applicable for organic production. No allowance was made for micronutrients potentially provided in forage, soil or from sunshine. Details are provided in the bulletin.

Dried forages

Dried forages can be included in a complete feed (e.g. Table 7.8). For many producers this is the most practical method of utilizing forage. Hammer mills equipped with screens set with 4.5–6.5 mm openings will provide the correct particle size. Pelleting diets that contain high amounts of forage will reduce separation and improve palatability and fibre digestion.

Table 7.5. Suggested dietary mixtures to supplement pasture for growing pigs of 20 to 55 kg live weight (from Kephart *et al.*, 1990).

	Type of pasture		
	Legume	Grass	Legume–grass mix
Ingredient (kg/t)			
Maize	727	693.5	708
Soybean meal (44%)	248.5	275.5	264
Ground limestone	2	7.5	5
Dicalcium phosphate	12.5	13.5	13
Salt (NaCl)	5	5	5
Vitamin premix	2.5	2.5	2.5
Trace mineral premix	2.5	2.5	2.5
Calculated analysis			
Metabolizable energy (kcal/kg)	3287	3260	3274
Metabolizable energy (MJ/kg)	13.75	13.64	13.7
Crude protein (g/kg)	171.0	180.0	176.0
Lysine (g/kg)	9.1	9.8	9.5
Calcium (g/kg)	4.8	7.0	5.9
Phosphorus (g/kg)	6.0	6.2	6.1

The above mixtures assume that the pigs will consume 0.34 kg pasture dry plus 1.7 kg dietary mixture per day; and that pasture and feed together will provide a minimum of 345 g protein, 18 g lysine, 13 g calcium and 11 g phosphorus per day.

Quality of the Meat

It is pertinent to consider how organic feeding, and access to herbage or pasture in particular, affects the quality of the meat. However, before doing so it is useful to review findings on the general effects of diet and feeding level on pork quality.

Effect of feed on pork flavour

Melton (1990) reviewed the effect of diet on pork flavour and categorized the relevant research since 1969 into five types: (i) studies in which the dietary protein and (or) energy levels were changed; (ii) studies in which the dietary grain source was changed; (iii) studies in which the type of dietary protein supplement was changed; (iv) studies in which different sources of dietary fat were used; and (v) studies in which minor dietary constituents were changed in concentration or to which trace constituents were added. As she pointed out, many of the experiments that involved alteration of the protein supplement also involved alteration of the energy level, grain source and (or) fat sources. For instance, the most common protein source for pigs is extracted soybean meal. Substitution of whole oilseeds such as groundnut, canola or sunflower for soybean meal alters not only the protein source but also the oil (fat) source.

A summary of the conclusions reached by Melton (1990) follows.

Effects of dietary protein and energy levels

One study involved the feeding of maize-based diets containing either 112 or 163 g protein/kg from extracted soybean meal and extracted flaxseeds. Pork produced from pigs fed the diets with the lower protein levels received higher overall desirability scores, although flavour was not assessed. In another study pigs were fed on maize-based diets containing 120, 160 and 200 g protein/kg and different energy levels by changing the level of soybean meal in the diet and by substituting 0–100% of the fat for dextrose. In contrast to the findings in the previous report, no significant effects of protein or energy level on the flavour desirability of pork loin were found. Although different protein and energy levels changed the ratio of fat to lean in pork muscle, it did not affect the flavour, a conclusion also reached by other researchers.

Table 7.6. Suggested dietary mixtures to supplement pasture for finishing pigs of 55 to 110 kg live weight (from Kephart *et al.*, 1990).

	Type of pasture		
	Legume	Grass	Legume–grass mix
Ingredient (kg/t)			
Maize	788	755.5	770
Soybean meal (44%)	185.5	212	200.5
Ground limestone	2.5	8	5
Dicalcium phosphate	14	14.5	14.5
Salt (NaCl)	5	5	5
Vitamin premix	2.5	2.5	2.5
Trace mineral premix	2.5	2.5	2.5
Calculated analysis			
Metabolizable energy (kcal/kg)	3293	3267	3280
Metabolizable energy (MJ/kg)	13.78	13.67	13.72
Crude protein (g/kg)	149.0	157.0	154.0
Lysine (g/kg)	7.4	8.1	7.8
Calcium (g/kg)	5.1	7.3	6.2
Phosphorus (g/kg)	6.0	6.2	6.1

The above mixtures assume that the pigs will consume 0.45 kg pasture dry plus 2.27 kg dietary mixture per day; and that pasture and feed together will provide a minimum of 410 g protein, 20 g lysine, 18 g calcium and 15 g phosphorus per day. Recommendations were also made on the feeding of silage and haylage (haylage can be made like silage from any crop that is traditionally stored as hay).

Table 7.7. Suggested dietary mixtures to supplement silage and haylage for gestating sows (from Kephart *et al.*, 1990).

	Type of silage	
	Legume haylage (450 g dry matter/kg)	Maize silage (330 g dry matter/kg)
Ingredient (kg/t)		
Maize	820.5	647
Soybean meal (44%)	145	299.5
Ground limestone		12
Monosodium phosphate	22.5	
Dicalcium phosphate		29.5
Salt (NaCl)	6	6
Vitamin premix	3	3
Trace mineral premix	3	3
Calculated analysis		
Metabolizable energy (kcal/kg)	3274	3179
Metabolizable energy (MJ/kg)	13.7	13.3
Crude protein (g/kg)	134.0	187.0
Lysine (g/kg)	6.3	10.4
Calcium (g/kg)	0.8	12.6
Phosphorus (g/kg)	8.1	9.2

The above mixtures assume that the pigs will consume 1.6 kg silage or haylage dry plus 1.15 kg dietary mixture per day; and that pasture and feed together will provide a minimum of 341 g protein, 17 g lysine, 18 g calcium and 14 g phosphorus per day.

More recent research has consistently shown an improvement in tenderness and eating quality of pig meat from animals with a high growth rate resulting from the *ad libitum* feeding of diets which are relatively nutrient-dense (Ellis *et al.*, 1996; Blanchard *et al.*, 1999; Edwards, 2005). As a result the general recommendation is that pigs should be grown fast to market, in order to maximize the eating quality of the meat. However, the improvements may not be large (Table 7.9).

Reduced levels of concentrate feeding and *ad libitum* intake of roughage (either clover grass or clover grass silage) are known to reduce daily gain in growing pigs, resulting in increased lean meat content but reduced intramuscular fat and tenderness (Danielson *et al.*, 1999; Hansen *et al.*, 2001). These carcass effects are probably not those that producers wish to achieve in organic pigs and the correct intake of nutrients needs to be maintained in pigs fed forage.

Grain source

As reported by Melton (1990) a sensory panel could not detect any difference in the flavour of country-cured hams from pigs fed primarily maize and those fed groundnuts in the hull, even though the ham fat produced by pigs fed the groundnut diet was much softer than that produced by pigs fed

Table 7.8. Suggested diets based on high levels of dried forages for gestating sows (from Kephart *et al.*, 1990).

Ingredient (kg/t)					
Maize	590	602	581	573	567.5
Soybean meal (44%)	116	104	178	135.5	144.5
Birdsfoot trefoil	250				
Red clover		250			
Kentucky bluegrass			250		
Orchard grass				250	
Ryegrass					250
Ground limestone	14	15	7	7.5	5.5
Monosodium phosphate	21	20			
Dicalcium phosphate			25	25	23.5
Salt (NaCl)	4	4	4	4	4
Vitamin premix	2.5	2.5	2.5	2.5	2.5
Trace mineral premix	2.5	2.5	2.5	2.5	2.5
Calculated analysis					
Metabolizable energy (kcal/kg)	2924	3018	2908	2908	2948
Metabolizable energy (MJ/kg)	12.23	12.63	12.17	12.17	12.33
Crude protein (g/kg)	142.0	145.0	138.0	136.0	133.0
Lysine (g/kg)	6.5	6.5	6.5	6.5	6.5
Calcium	10.0	10.0	10.0	10.0	10.0
Phosphorus	7.7	7.7	7.7	7.7	7.7

Table 7.9. Effects of *ad libitum* and restricted feeding regimes on eating quality of pork (from Ellis *et al.*, 1999).

Trait	Advantages on pork quality of *ad libitum* feeding over restricted feeding: Data of Warkup *et al.* (1990)	Data of Ellis *et al.* (1996)
Tenderness	0.47	0.30
Juiciness	0.19	0.26
Flavour	−0.05	0
Odour	0.02	0.12
Overall acceptability	–	0.19

Advantage based on a scale of 1 (lowest) to 8 (highest).

maize. This result was confirmed by other research which showed that meat from pigs allowed to glean peanuts remaining in the field as a growing diet did not have a more intense flavour than meat from pigs fed a maize/soybean meal-based diet. The effects of different dietary ratios of barley and roasted soybeans were compared with those of maize and soybean meal on the flavour of cooked pork longissimus muscle. No significant dietary effect on flavour desirability of the pork was found, and the flavour of all of the pork samples was rated by a trained sensory panel as ‘liked moderately’ to ‘liked very much’. Related work studied the effect of maize, wheat, milo and barley diets, each supplemented with protein from soybean meal or infrared-heated whole soybeans, on pork flavour. Results showed that source of protein did not affect flavour desirability score, but pork from pigs fed the milo diet had a less desirable flavour than the pork from pigs fed maize, barley or wheat, although it was liked moderately. Other grains that have been studied as replacement for part or all of the maize in pig diets include triticale and naked oats (Melton, 1990). Pigs were fed on maize-based diets in which 0, 20, 40, 60 and 80% of the maize was replaced with triticale without any effect on flavour desirability of the longissimus muscle being recorded. Naked oats were substituted for 0, 50 and 100% of the dietary maize in another study. A panel of ten experienced panellists scored the flavour of pork from pigs fed the 100% naked oats diet as being more intense than from pigs fed the maize diet. However, flavour desirability scores were not determined.

The above studies indicate that feeding different grains to pigs affected meat flavour in some studies but not in others. Diets based on milo (sorghum) produced a less desirable flavour than when based on maize, wheat or barley. Triticale in combination with maize gave results similar to those with maize alone as the dietary grain. Diets based on naked oats produced pork with a more intense flavour than diets based on maize; however, it was not clear from the study in question as to whether the flavour was more or less desirable.

Protein source

Several studies reviewed by Melton (1990) showed that replacement of soybean meal in the diet by cooked whole soybeans did not affect pork flavour. In contrast another report found that diets containing raw soybeans at up to 50 g/kg had no adverse effect on pork palatability but that inclusion of raw soybeans in excess of 90 g/kg in a barley-based diet to boars increased the incidence of off-flavour in loin roasts. One factor that may have influenced this result is the unstable nature of the oil in soybeans, which can become oxidized and result in off-flavours.

Other findings reviewed by Melton (1990) suggest that several protein supplements may replace soybean meal in the diet without effect on meat flavour. Soybean meal was replaced with extracted canola meal in a barley-based diet at several different levels (150, 170 and 190 g/kg). Neither the intensity of pork flavour nor intensity of any foreign flavour in the pork fat or lean was affected by protein source or concentration. Out of 952 ratings made in this experiment by 14 panellists, 61 abnormal flavour ratings were recorded in total for the meat produced by pigs fed the soybean meal and 56 for meat produced by pigs fed the canola meal. In another study soybean meal in a barley-based diet was replaced with each of two cultivars of lentils. Inclusion of lentils up to 200 g/kg in the diet did not affect meat flavour, but when lentils were included in the diet at 300 and 400 g/kg, the flavour of the pork was inferior.

It has been known for a long time that fishmeal should not be included in diets at levels higher than 50 g/kg because it gives a fishy flavour to pork, although the effect is reduced or eliminated if the fishmeal is removed from the diet at least 2 weeks prior to slaughter. Incorporation of fish by-products into fish silage may allow higher levels of fish to be added to the diet without causing a fishy flavour in pork.

Fat source

As pointed out by Melton (1990), in many of the reports reviewed the level and type of fat fed to pigs were altered because of the changes in the grain or protein source. Feeding pigs on diets containing groundnuts in place of maize was found to increase the degree of unsaturation of the backfat due to an increase in the concentration of oleic (18:1) and linoleic (18:2) fatty acids and an associated decrease in palmitic (16:0) and stearic (18:0) acids. However, there was no effect on pork flavour. Also, the feeding of increasing levels of triticale combined with maize did not affect flavour, even though the composition of the pork fat was altered. Added triticale increased the percentage of palmitoleic (16:1) and 18:2 fatty acids but decreased the percentage of 16:0 and 18:0 fatty acids in backfat and longissimus muscle lipids. The percentage of 18:1 decreased in backfat, but increased in muscle lipid.

Other investigations reviewed by Melton (1990) have found that feeding pigs different dietary fat sources affects fatty acid composition but not pork flavour, e.g. that substituting sunflower seed (0–200 g/kg diet) for soybean meal and maize increased the content of 18:2 from 15.9 to 33.3% and decreased that of 16:0 from 26.0 to 19.4%, of 18:0 from 11.9 to 9.4% and of 18:1 from 42.8 to 35.0% in backfat. However, there was no effect on meat flavour. A similar result was obtained with full-fat cooked soybeans at up to 300 g/kg diet. Melton (1990) reported one study in which the opposite effect was found. The inclusion of naked oats in a maize-based diet increased the flavour intensity of the meat and affected the fatty acid composition slightly. The concentrations of 16:1, 18:2 and linolenic acid (18:3) decreased slightly with increasing levels of naked oats, whereas the concentration of gadoleic acid (20:1) decreased.

Some researchers, however, reported that both pork fatty acid composition and flavour can be affected by dietary fat source. In one study (Melton, 1990) it was found that feeding fishmeal and/or oil from marine sources to pigs markedly increased the levels of the long-chain n–3 PUFA 20 : 4n–3, 22 : 5n–3 and 22 : 6n–3 in pork and that the intensity of off-flavour increased with increasing levels of fishmeal or fish oil in the diet. Also, more than 5 g PUFA/kg in bacon fat resulted in a fishy flavour.

As noted above, the inclusion in pig diets of raw full-fat soybeans at more than 90 g/kg was reported to increase the incidence of off-flavours in the meat. Other researchers have not reported this effect when the soybeans were cooked, suggesting that lipoxygenase-catalysed oxidation of soybean oil in the uncooked soybeans during diet preparation probably caused the off-flavours, not the soybeans per se.

Changes in pork fatty acid composition related to changes in the diet generally have been associated with no change in pork flavour intensity or desirability. It seems surprising that high levels of 18:2 in pork fat from dietary groundnuts, sunflowers and cooked whole-fat soybeans did not cause an oxidized flavour in pork that was objectionable to sensory panels. Melton (1990) suggested that perhaps because pork fat is already unsaturated compared with fat in other red meats, oxidative rancidity is part of an acceptable or intense pork flavour.

Several investigations have studied the effect of specific fatty acids on meat flavour, e.g. diets containing 0, 100 or 200 g canola oil/kg. Compared with the control, feeding the diet with canola oil at 200 g/kg increased 18:1 in the longissimus muscle lipid from 48.6 to 56.6% and 18:2 from 6.2 to 18.3% but decreased 18:0 from 8.6 to 3.5% and 16:0 from 31.8 to 18.8%. These changes did not alter the flavour intensity of the meat, but it was found that addition of whole canola seed at 150 g/kg to a barley-based diet resulted in an increase in 18:1 from 48.7 to 51.9%, in 18:2 from 9.0 to 14.9% and in 18:3 from 0.4 to 3.4%, with associated decreases in the levels of 16:0 and 18:0. The study in question did not investigate meat flavour. These results were similar to those reported previously for fatty acid composition of backfat from pigs fed a diet containing 100 g canola oil/kg, with no associated effects on meat flavour. Another study involved three different combinations of beef fat and soybean oil in the diet to produce backfat containing 10% (normal), 20% (medium) or 30% (high) concentrations of 18:2. It was found that a consumer panel preferred the taste of back bacon made from pigs fed the normal or the high 18:2 diet. However, they preferred the taste of pork loin roll from pigs fed the diet with the medium 18:2 level over that from pigs fed the diet with the normal level of 18:2.

As outlined above, it is relatively easy to alter the fatty acid composition of the backfat using the type of diet used in organic production, i.e. containing fat from plant sources that is high in PUFA. The presence of PUFA in the fat of pigs indicates their presence in the diet, since pigs fed a diet containing no fat or a low level of fat synthesize and deposit saturated (mainly 16:0 and 18:0) and monounsaturated (18:1) fatty acids. The study of Cameron and Enser (1991) provided more information on how this might influence the eating quality of the meat. They found that the correlations between the concentrations of specific fatty acids in the intramuscular fat and meat quality traits were generally weak. Correlations between PUFA and palatability scores were generally negative and those between the saturated fatty acids and palatability were generally positive. These results suggest that the higher the degree of unsaturation of the intramuscular fat the lower the palatability score and the greater the incidence of abnormal flavours. These results might not be related to the fatty acid profile *per se* but to oxidation of the fatty acids and the development of rancidity. The findings are of obvious interest to the organic producer.

Miscellaneous sources

Other, more exotic, treatments have been investigated as a means of affecting pork flavour. For instance Cullen *et al*. (2005) studied the effects of inclusion of rosemary (*Rosmarinus officinalis*) and garlic (*Allium sativum*) in diets for growing-finishing pigs on apparent nutrient digestibility, growth performance, carcass characteristics and sensory characteristics of the pork. The diets used were a diet unsupplemented or supplemented with rosemary at 1 or 10 g/kg or with garlic at 1 or 10 g/kg. Pigs given both garlic diets had significantly lower feed intake than pigs given the control or rosemary diets. DM digestibility and organic matter digestibility were lower with the high-garlic diet than with the low-garlic diet, and the inclusion of a high level of rosemary in the diet resulted in a lower digestibility of energy than with the low level of rosemary. According to the published abstract of the study, sensory panellists found a significant difference in the sensory properties of cooked muscle from the control and high-garlic treatments. However no details were provided on whether the difference was positive or negative (leaving the reader to ponder whether the garlic should be fed to the pigs while alive or used on the meat while it is cooking!).

Effect of organic feeding on pork meat quality

The above findings confirm that diet can have an important effect on the amount and fatty acid composition of fat in the pig carcass. This has important implications for the organic producer, mainly in terms of the keeping quality of the meat and its suitability for further processing. However, dietary composition appears to have minimal or no effects on the flavour of the meat itself.

The suggestion has been made that pork fat with an enriched content of PUFA is more desirable for the consumer in that it would help to promote better health. This is relatively easy to achieve as PUFA are readily incorporated in pork fat. Studies outlined above have demonstrated that this can be achieved by the use of feedstuffs such canola seed, linseed or soybeans.

A review of the effects of organic production on pork composition was conducted by Średnicka-Tober *et al.* (2016) which showed that the main change was an altered fatty acid profile in the organic pork. An estimate of the effect of this change on specific fat intakes by the average consumer consuming 19.1 g fat from pork daily is shown in Table 7.10.

Effects of organic production on other compositional changes to pork (pesticides, vitamins, minerals – with the possible exception of copper) were found to be insignificant.

These changes in fat composition can be obtained in a relatively short time. Pork fat enhanced in this way could be a selling feature for organic pork. However, it would be important to ensure that the animal had a high intake of vitamin E to prevent oxidative changes in the fat and to market the meat soon after production to avoid rancidity of the fat. Such meat would be best used fresh and not stored or used for further processing.

In addition, high amounts of PUFA from oilseeds, oilcakes and grass of the *n*–6 (linoleic acid) or *n*–3 (linolenic acid) family can have deleterious effects on meat softness, meat storage stability and quality (Jakobsen, 1999). Therefore, the quality of organically produced meat can be a matter of concern, especially its fatness and the palatability.

It seems clear from the research conducted to date that the amount and composition of carcass fat can be altered by diet in the pig, but what about the meat? Does organic feeding have an effect on meat quality,

Table 7.10. Estimated fatty acid intake (mg/person/day) from organic and conventional pork (from Średnicka-Tober *et al.*, 2016).

	Organic	Conventional	Difference %
Saturated fatty acids (SFA)	6648	6868	–3
14:0 (myristic acid)	217	252	–16
16:0 (palmitic acid)	4328	4368	–3
Mono-unsaturated fatty acids (MUFA)	8229	8417	–2
Poly-unsaturated fatty acids (PUFA)	2930	2561	14
n-3	419	360	16
n-6	4400	3637	21

particularly flavour? There are several anecdotal reports of certain feedstuffs, e.g. groundnuts, imparting a distinctive taste to pork. Reports such as these are of interest to organic producers. What is the evidence? Much of the attractiveness of organic produce stems from its freshness at the retail level, but apart from that what is the effect of diet on the main determinants of pig meat quality? This is addressed in the following section, from an organic perspective. The topic is too large for an in-depth review in the present context and readers are advised to study publications on meat science for more complete information.

The appeal of organic pork for the consumer is based on several attributes, as discussed previously. In assessing the effects of diet it is clear that the different effects on meat quality have to be considered separately. A dietary change may increase the content of intramuscular fat but at the expense of tenderness. In addition, the effects on meat quality have to be weighed against production effects. For instance, it is known that diets deficient in protein or in limiting AA result in increased marbling in pig muscle (Pettigrew and Esnaola, 2001). For instance, D'Souza *et al.* (2002) raised the content of intramuscular fat in the longissimus thoracis muscle from 13 to 19 g/kg by reducing the protein:energy ratio of the diet by 15%. However this effect is usually achieved at the expense of growth rate and leanness of the carcass.

Effect of forage-based diets on meat quality

Roughage intake can be beneficial to pig welfare, with bulky diets promoting satiety when feed intake is limited (Edwards, 2005). They may also influence health beneficially through both the promotion of a desirable gut microflora profile and a reduced incidence of gastric ulceration (Lee and Close, 1987). However, do pigs derive a substantial amount of nutrients from this source, enough to require that the dietary composition be altered? The forage (or roughage) may be in the form of grazed vegetation or supplementary feed silage or root crops.

Animals fed regular dietary mixtures *ad libitum* have been found to have very low forage intakes (< 5% of daily DM intake; Edwards, 2003). When the regular feed is restricted, higher intakes of roughage can be achieved (up to 15%). Effects of herbage consumption on meat quality are still little explored. Herbage contains compounds with the potential to flavour pig meat, as well as unsaturated fatty acids and antioxidants. Pigs given access to pasture have higher levels of PUFA, *n*–3 fatty acids and vitamin E in the muscle than indoor pigs (Nilzen *et al.*, 2001; Hogberg *et al.*, 2002). This gives the positive advantage of a meat product which can be considered more beneficial for human health, but which also has the potential for higher lipid oxidation in storage, with adverse effects on organoleptic quality. However, direct nutritional effects of herbage may be accompanied by indirect negative effects on total nutrient intake and growth rate associated with feeding of bulky diets. Research has consistently shown an improvement in tenderness and eating quality of pig meat from animals with high growth rate resulting from *ad libitum* feeding of diets which are relatively nutrient-dense (Ellis *et al.*, 1996; Blanchard *et al.*, 1999). This may be associated with increased protein turnover rate, proteolytic activity in muscle, and reduced collagen maturity at slaughter. Reduced levels of concentrate feeding and *ad libitum* intake of roughage (either clover grass or clover grass silage) caused reduced daily gain in growing pigs, which caused increased lean meat content and reduced intramuscular fat and tenderness significantly (Danielson *et al.*, 1999; Hansen *et al.*, 2001). Hansen *et al.* (2001) found no significant effects on meat and eating quality between low concentrate rations including *ad libitum* intake of roughage compared with a 100% organic concentrate or a 100% conventional concentrate, except for the composition of fatty acids. PUFA in the meat of 100% organic fed pigs increased significantly by 2% compared with those fed 100% conventional concentrate. Feeding restricted amounts of organic concentrate and unrestricted amounts of roughage further increased the amount of PUFA by 4% in comparison with the conventional concentrate feeding treatment. This increase may lead to healthier meat, but also rancidity and a problem of 'warmed-over flavour' during storage and processing of the organic meat. In a study of eating quality of pork and pig meat products of organic pigs kept at pasture or in a shed-and-run system (Kelly *et al.*, 2001), no consistent differences were detected as a result of access to fresh herbage. Because of the difficulty in obtaining dietary protein of high quality produced under organic conditions, it is more likely that organically reared pigs will receive a reduced supply of the limiting EAA. This regime has been shown to result in increased intramuscular fat content (2.9 versus 1.2%), and therefore possibly improved eating quality, under experimental conditions (Sundrum *et al.*, 2000a). However, it has not yet been possible to replicate these results under farm conditions (Sundrum *et al.*, 2000b).

Regarding production systems, pork reared outdoors was slightly juicier than pork reared conventionally, but no differences in tenderness, odour and flavour were found (Lebret *et al.*, 2006).

Mediterranean silvopastoral systems have been associated with improved quality of pig meat when used for dry-cured ham production, due to the relatively high levels of intramuscular fat resulting from access of native pig breeds to acorns which are high in starch (Edwards and Casabianca, 1997). Cava *et al.* (1999) showed increased aroma and flavour, and less rancidity in dry-cured ham, by feeding acorns to pigs. Within a given genotype, many studies have been carried out to show how the characteristics of the fat are modified during the finishing regime, with eating quality particularly affected by the accumulation of 18:1 in the adipose tissue (Fallola *et al.*, 1989). Genotype–environment interactions occur, since a Large White, even after acorn finishing, never exceeds 2.5% intramuscular fat, whilst a native pig of slow growth genotype subject to such finishing can reach 11% (Casabianca and Luciani, 1989).

Since many component factors that have been shown to influence pig meat quality can differ between indoor and outdoor systems, measurable differences between animals from such systems might be expected. However, evidence of any consistent effect is sparse.

A large-scale investigation conducted by the Danish Pig Production and the Danish Meat Research Institute (Søltoft-Jensen, 2010) found that organic feed affected tenderness as well as the colour and taste of pork chops. Two organic diets were tested, one with 80% inclusion of organic ingredients and the other 100%. The reason for two organic diets was that the European organic regulations then allowed some non-organic feedstuffs to be used because of a scarcity of organic ingredients.

Blair (2011) reviewed the findings and reported that:

> [T]he conventional pork chops were more tender, appeared more crumbly and less crisp and stringy than chops from pigs fed organically. Chops from the 100% organically fed pigs differed from chops from the 80% organically fed pigs by being less tender, having a greater bite resistance/toughness and by being less crumbly. The difference between chops from 100% organically-fed and conventionally-fed pigs was as much as 3.7 units, a difference that would be detected by the average consumer. Chops also had a different taste. Those from pigs fed the 100% organic diet tasted more 'piggy' and had more of a metallic odour than chops from pigs fed the 80% organic or conventional diet. Colour measurements showed that meat from pigs fed the conventional diet was lighter than the meat from pigs fed the two

Fig. 7.4. Organic pork chops from traditional breeds have an enhanced flavour. (Photo courtesy of Dr Hobo, via Flickr, under a CC BY-ND 2.0 licence.)

organic diets. The difference in colour between meat from conventionally fed pigs and the 80% organic feed pigs would not be noticed by the average consumer. However, meat from pigs fed 100% organic feed was considerably darker than the meat from the other two groups of pigs and would be noticed by the consumer.

The Danish researchers suggested that the differences in meat tenderness and meat colour were most likely related to differences in the growth rate of the pigs. Research in Denmark and in other countries has shown that at a large gain in muscle development prior to slaughter results in an increase in meat tenderness. Investigations have also shown that a reduced rate of weight gain affects the colour of the meat.

Eleven different published experiments reporting comparisons of meat quality in outdoor- and indoor-reared pigs have been reviewed by Edwards (2005). The majority of studies where the measurement was reported (6/9 and 7/10) have shown no difference in juiciness and tenderness, respectively. Three studies reported reduced juiciness in outdoor pigs; one reported reduced tenderness, while two reported increased tenderness. Detrimental effects on meat quality have sometimes been linked with reduced growth rate and/or fatness. No experiments (0/7) showed a difference in (meat) flavour and only one (1/4) reported a difference in off-flavour or taint. A significant number (6/9), however, have reported reduced muscle pH and/or increased drip loss, suggesting greater susceptibility of outdoor pigs to pre-slaughter stress.

One feeding method that has been investigated as a way of improving pork tenderness is compensatory growth, i.e. an accelerated growth rate with *ad libitum* feeding following a period of restricted feeding. The concept behind this procedure is that higher rates of protein synthesis and degradation are known to improve meat tenderness (Skiba *et al*., 2006). However, a large international study co-ordinated in Ireland (Downey *et al*., 2007) found that while feed restriction and subsequent compensatory growth had a slightly beneficial effect on pork tenderness, it had deleterious effect on production performance compared with *ad libitum* feeding since compensatory feeding only made up for about 40–70% of the growth retardation caused by restricted feeding. As a result it could not be recommended economically.

The research also showed that growing pigs have a distinct preference for concentrate feed relative to roughage, regardless of its quality/palatability.

Diet and Disease Prevention

Although organic pigs with outdoor access or housing are theoretically exposed to a greater disease risk, studies conducted in several countries have shown no consistent difference between conventional and organic pig production systems in the incidence of bacterial food-borne pathogens, including *Salmonella enterica*, *Campylobacter jejuni*, *Campylobacter coli*, *Listeria monocytogenes*, and *Yersinia enterocolitica* (Rostagno, 2011).

Organic producers can take several nutrition-related steps to control health problems in their herds. These can be summarized as follows and readers are directed to veterinary publications for a more detailed outline of the appropriate procedures.

A logical first step is to breed from healthy stock and maintain a closed-herd policy, if possible. The buying-in of semen rather than live animals will minimize the risk of importing diseases. Also, pastures should be maintained and rotated correctly, to minimize parasitism. Organic pigs are then more likely to be healthier than pigs grown conventionally, especially weaners due to the longer suckling period on the sow. An adequate space allowance and fresh air will reduce infection pressure but if ground conditions become poor as a result of high rainfall and unsuitable soil type welfare may be seriously compromised.

Roughage intake can be beneficial to pig welfare, with bulky diets promoting satiety when dry sows and boars have to be fed restricted rations. These diets may also influence health beneficially, through both the promotion of a desirable gut microflora and a reduced incidence of gastric ulceration.

A recurring problem with young pigs is gastrointestinal disease, especially after weaning. Feed-related approaches to this problem include trying to improve immunity to diseases, adding fibre to the diet to encourage fermentation in the large intestine, and supplanting disease organisms in the gut with beneficial organisms. The aim is to allow the intestinal epithelium and host microflora to act as natural barriers to damage from pathogenic bacteria, antigens and toxic substances inside the gut.

Prebiotics

There is current interest in animal and human nutrition in the use of so-called functional foods or prebiotics as dietary components. These are feeds (and foods) that have been shown to affect beneficially one or more target functions in the body beyond nutritional effects, to improve health and well-being and/or reduce the risk of disease.

Belonging to this group are chicory and Jerusalem artichoke, which contain inulin-type fructans in the sap and roots. These fructans are resistant to enzymatic degradation but have been shown to ferment in the large intestine with beneficial effects on gut health by modifying the gut microflora, and are regarded as a possible alternative to antibiotics in the feed. The inulin-type fructans and other compounds of a similar nature may be of particular application in starter diets for weaned pigs, to help cope with gastrointestinal problems. Part of the reasoning for the use of dietary fibrous sources that ferment in the large intestine is that they may produce butyrate, a short-chain fatty acid (SCFA). Butyrate and other SCFAs are important for the absorption of electrolytes by the large intestine and may play a role in preventing certain types of diarrhoea (and cancer in humans). Some herbs such as allium, thymus, anhriscus and ferule are also known to stimulate acid production by lactobacilli and might be useful prebiotics for use in animal and human nutrition.

Dierick *et al.* (2004) investigated the mode of action of medium-chain fatty acids (MCFA) and benzoic acid on the gastrointestinal flora and gut health of newly weaned piglets. Piglets weaned at 4 weeks of age and with a mean live weight of 8.7 kg were fed: (i) a control diet (C); (ii) the control diet supplemented with 24 g medium-chain triglycerides (MCT) plus 1 g lipase per kg; or (iii) the control diet supplemented with 10 g benzoic acid (B) per kg. Average daily weight gain and feed conversion ratio (0–11 or 12 days post-weaning) of piglets fed with C, MCT and B were 234 g and 1.39, 278 g and 1.29, and 297 g and 1.32, respectively; the differences were not significant. Feeding the MCT diet resulted in lower bacterial counts, including favourable lactobacilli and bifidobacteria, while diet B did not affect the bacterial flora. This result agreed with the findings of bactericidal concentrations of free MCFA amounting to 4.1 g per kg of gastric contents with the MCT diet. Lactate concentration in the proximal jejunum, distal jejunum and caecum was considerably lower when the MCT diet was fed, but diet B had no influence on these measures. The authors concluded MCFA released *in situ* in the piglet foregut reduced the bacterial load in the gut, with a positive influence on performance.

Verdonk *et al.* (2005) reviewed research findings on the use of inulin-type fructans in pig diets. In these experiments different types of fructans and other prebiotics were supplied in the feed or drinking water to pigs alone or in combination with a probiotic. Supplementation was found to result in fewer cases of diarrhoea, reduced mortality and decreased number of pigs shedding pathogenic organisms, compared with controls. A growth response was observed in some studies. Results on alteration of the gut microflora have been mixed. Some studies found that supplementation with inulin-type fructans had little effect on size and activity of microbial populations but others found enhanced intestinal bifidobacteria populations. Other studies reported modulation of the intestinal flora and speeding up of recovery of the normal intestinal microflora following acute diarrhoea. Piglets fed diets containing sugarbeet pulp (10 g/kg) or inulin-type fructans plus sugarbeet pulp (2.5 + 5 g/kg) showed a higher bacterial diversity and a more rapid stabilization of the bacterial community than pigs fed a control diet based on maize starch. One study demonstrated that the combination of insulin-type fructan and probiotics given to pigs before and after birth enhanced the immune response. Inulin supplementation was also found to reduce the *in vitro* association of *E. coli* to jejunal organ tissue, the association of *Salmonella* spp. to ileal tissue, and the *in vitro* adhesion of a pathogenic coliform to intestinal porcine mucosa. One study involved an investigation of the effect of supplementation of spray-dried animal plasma and inulin-type fructans on the morphology of the small intestine in weaned pigs.

Shim *et al*. (2005) conducted a study to determine whether feeding an antibiotic-free creep-feed supplemented with oligofructose (OF), probiotics or a combination of both to suckling piglets influenced growth performance, the gut microflora, gut morphology and haematological traits at weaning. The four treatments were: control diet (antibiotic-free); control diet plus 2 g OF/kg; control diet plus 3 g probiotics/kg; or control diet plus a combination of both. Piglets were given the diet *ad libitum* from 7 days after birth until one day after weaning at 21 days of age. At the day after weaning, blood samples were collected from the jugular vein to determine the immune response. Digesta samples of the ileum and colon were collected to determine the microbial composition. Tissue segments from the duodenum and ileum were collected for morphometric measurements of the small intestine.

The results showed that average daily weight gain was significantly higher for piglets fed the diet containing OF or the combination diet compared with pigs fed the control diet (Table 7.11). The concentration of lymphocytes and neutrophils in whole blood was not affected by diet. Piglets fed the OF, probiotics or combined diet had a significantly decreased number of total coliform bacteria in the colon. Feeding OF, probiotics or a combination significantly increased the population of bifidobacteria in the ileum and colon.

The improved growth rate in this study may be the result of beneficial effects of the additives on gut health parameters by stimulating beneficial bacteria, especially bifidobacteria, and decreasing coliforms. No data on feed intake were presented, which might have helped to explain the growth response. Although some beneficial effects were found from each additive, there was no additional benefit of the combination over the OF or the multi-strain probiotic supplement. There were no significant differences in lymphocyte and neutrophil concentrations in the blood. This result was in agreement with other reports where neither dietary inulin nor probiotic was found to affect the immune response in weaned pigs.

Piglets receiving dietary OF had a higher villous height in the small intestine at weaning. This finding was regarded as important since villous height in the small intestine is regarded as an indicator of nutrient absorption in pigs. If a good villous height can be maintained during the weaning transition, nutrient digestibility might be optimal. Villous height is known to be positively correlated with weight gain, nutrient intake level and the health status of weaned pigs. However, this study found no significant correlation between growth rate and villous height. The population of bifidobacteria in the ileum was significantly higher after supplementation of OF and probiotics singly or in combination, and in the colon after supplementation of probiotics singly or in combination. These effects were interpreted as being beneficial, in that increased bifidobacteria may help to suppress potentially pathogenic bacteria.

Van Nevel *et al*. (2005) investigated the influence of galactomannans on bacteriological and morphological aspects of the gastrointestinal tract in weanling pigs. Four groups of five newly weaned piglets received one of the following diets: control feed (C); C supplemented with guar gum (1%); C supplemented with locust bean gum (1%); and C supplemented with 10% carob tree seeds meal as source of locust bean gum. Total counts of bacteria in digesta and mucosal scrapings were not influenced by the different diets, with the exception of the proximal jejunum where a small decrease (0.5 $\log_{10}$

Table 7.11. Effect of dietary inclusion of oligofructose (OF) and probiotics, singly or in combination, on the growth performance, gut microflora, gut morphology and haematological traits of nursing piglets (from Shim *et al.*, 2005).

	Control	OF	Probiotics	Combined
Growth performance				
Weight at start (2 days) (kg)	1.47	1.54	1.49	1.52
Weight at 21 days (kg)	5.25	5.79	5.55	5.82
Gain (g/day)	199	224	214	226
Haematological parameters				
Lymphocytes (%)	33.50	33.75	30.25	27.50
Neutrophils (%)	59.50	61.75	63.50	61.25
Ratio neutrophils: lymphocytes	1.94	1.84	2.52	2.43
Duodenum				
Villous height (μm)	319	380	302	331
Crypt depth (μm)	290	378	300	333
Ileum				
Villous height (μm)	250	349	278	400
Crypt depth (μm)	250	350	283	403
Ileal microflora (CFU)				
Total coliforms	NA	NA	NA	NA
Lactobacilli	7.40	7.77	7.53	7.74
Bifidobacteria	6.40	8.87	8.23	8.10
Colonic microflora (CFU)				
Total coliforms	7.18	6.30	6.50	6.05
Lactobacilli	8.71	7.79	8.38	8.62
Bifidobacteria	6.71	6.83	7.53	7.62

CFU, colony-forming unit; NA, not available.

CFU, where CFU is colony-forming unit) was noted with the diets containing guar gum and carob tree seeds. The number of *E. coli* increased by feeding diets with both gums and carob tree seeds. With the latter diet, higher counts of streptococci were observed. In agreement with the lower concentration of lactic acid in jejunal contents, guar gum decreased the number of lactobacilli. Locust bean gum decreased the molar proportion of acetate in caecal contents while butyrate and valerate were augmented. Feeding the carob tree seeds resulted in shorter villi and a lower villus height:crypt depth ratio in the jejunum mucosa, which was an indication for a faster renewal rate of the epithelium. Both locust bean gum feeds significantly lowered the mitotic index in the crypts of the small intestine. Viscosity of jejunal contents was increased with the diet containing carob tree seeds.

Several other experiments have been conducted with dietary oligosaccharides. An experiment was conducted with newly weaned piglets (Mikkelsen and Jensen, 2004) to study the effect of fructo-oligosaccharides (FOS) and transgalacto-oligosaccharides (TOS) on microbial populations and activity in the gastrointestinal tract. This work showed less of an effect on the intestinal microflora. Piglets aged 28 days were fed a control diet or the control diet supplemented with 40 g FOS or TOS per kg. After 4 weeks, the piglets were slaughtered and the gastrointestinal contents were removed for analysis. Results demonstrated that the yeast count was increased significantly in the distal small intestine, caecum and colon of piglets fed the FOS diet ($P < 0.05$) and throughout the gastrointestinal tract of piglets fed the TOS diet ($P < 0.01$). Bifidobacteria were isolated from 24 of the 27 piglets investigated. The density of bifidobacteria was not significantly affected by the experimental diets, nor were the populations of anaerobic bacteria, lactobacilli or enterobacteria. The FOS diet affected fermentation patterns in the caecum and proximal colon, resulting in significantly higher molar proportions of butyric acid ($P < 0.05$) and lower molar proportions of acetic acid ($P < 0.05$). The authors concluded that neither FOS nor TOS have any strong prebiotic effect on the population of bifidobacteria in the gastrointestinal tract of piglets.

The effects of dietary FOS (derived from chicory) and TOS (derived from whey) were studied on the growth performance and faecal characteristics of young growing pigs (Houdijk *et al.*, 1998). The dietary levels of these products were 7.5 and 15 g/kg diet for FOS, and 10 and 20 g/kg diet for TOS. The diets were fed *ad libitum* to 9-week-old castrated male piglets of initial body weight 15.6 kg. DM intake and body weight gain of the treated pigs were lower than those of the control pigs in week 1 to week 3. Dietary treatment did not affect mean growth performance in weeks 1–6. FOS and TOS could not be detected in the faeces. Dietary treatment did not affect faecal pH, but the treated pigs had lower faecal DM content than control pigs. Pigs fed TOS-rich diets had a lower faecal DM content than pigs fed FOS-rich diets. The authors concluded from this experiment that supplementing the diet of young growing pigs with oligosaccharides results in a temporary depressed feed intake with little or no effects on faecal DM content and pH.

Smiricky-Tjardes *et al.* (2003) found that ileal and overall digestibility of DM and organic matter were decreased by addition of either galacto-oligosaccharides or TOS to the diet of young pigs but that the gut microflora was affected beneficially.

None of the above studies involved a challenge with pathogenic organisms, which would have provided valuable information on how well infected animals given diets or drinking water supplemented with inulin-type fructans and other oligosaccharides cope with exposure to enteric disease organisms. Sugarbeet pulp is known to contain fructans; therefore organic producers should consider adding this product to sow and starter diets as a possible means of preventing and dealing with outbreaks of enteric disease.

Brewer's dried yeast, a source of MOS, has also been investigated as an alternative to an antimicrobial agent (carbadox) for young pigs (White *et al.*, 2002). The yeast contained 52 g MOS/kg. Tests showed that this product was capable of adsorption of several serovars of *E. coli* and *Salmonella* spp. In this study 22-day-old pigs were fed a non-medicated basal diet or the basal diet with carbadox (55 mg/kg), yeast (30 g/kg) or a combination of 30 g yeast and 20 g citric acid per kg for 28 days. Results showed that carbadox did not improve growth performance and that growth rate and feed intake were depressed in pigs fed yeast alone or in combination with citric acid. Log counts of total coliforms, *E. coli* and *Clostridium perfringens* in faeces were not affected by diet, but *Bifidobacteria* spp. counts were lower in pigs fed the yeast+acid diet and lactobacilli counts were higher in pigs fed yeast. Serum immunoglobulin G levels were elevated in the yeast+acid group, suggesting enhanced immunity. In a second experiment the pigs were fed the diets for 29 days and then each pig was dosed orally with approximately 9.5×10^8 CFU of *E. coli* K88. Yeast reduced colonization of total coliforms in the duodenum, jejunum, caecum and colon, but it did not have a consistent effect on colonization of *E. coli* K88. The researchers concluded that brewer's dried yeast and carbadox had minimal effects on growth, microbial populations and intestinal health traits of early-weaned pigs, but certain serum immunological traits were enhanced by feeding yeast. Further work on MOS by Burkey *et al.* (2004) showed that inclusion of this product in the diet prior to a disease challenge offered some protection against acute enteric disease but was not as effective as carbadox to challenge with *Salmonella enterica* serotype Typhimurium.

All of the studies reviewed indicate some benefit to gut health from the addition to the diet of nutritional components in brewer's yeast, various plants and root crops, and whey.

Probiotics

Certain probiotics have been approved for use in organic diets, provided they have not been derived using GM technology. A probiotic is defined as 'a preparation or a product containing viable, defined microorganisms in sufficient number, which alter the microflora (by implantation or colonization) in a compartment of the host, and by that exert beneficial health effects on the host' (Roselli *et al.*, 2005). The description implies that probiotics should be able to survive exposure to the digestive juices and that an adequate dose is necessary to have beneficial effects. The best-known characteristics of probiotics are the following: a capacity to adhere to intestinal mucosa and to inhibit pathogen adhesion, ability to transiently colonize and proliferate in the intestine, prevention of some intestinal diseases such as diarrhoea, and modulation of the immune system of the host (Roselli *et al.*, 2005). The rationale for probiotics use is that they are able to restore normal microflora.

The mechanisms by which probiotics (and prebiotics) produce beneficial effects on the gut have not yet been fully elucidated. However at least three mechanisms of action have been proposed: (i) antibacterial agents produced by probiotic organisms may have an inhibitory effect on pathogenic microbes; (ii) immune responses may be enhanced to suppress potential pathogens; and (iii) competition in the gut epithelium may allow lactobacilli and bifidobacteria to supplant pathogenic organisms.

Only a few probiotics have been tested for their capacity to prevent intestinal diseases in pigs, according to the review of Roselli *et al.* (2005). Some authors found that oral administration of *Streptococcus faecium* to germ-free piglets challenged with various pathogenic strains of *E. coli* led to increased weight gain, less severe diarrhoea and reduced colonization of pathogenic bacteria in the gut compared with control animals. A protective effectiveness of *Bifidobacterium lactis* was found in piglets, resulting in lower concentrations of faecal rotavirus and *E. coli* and a lower severity of diarrhoea following probiotic treatment. Other work has shown that supplementation of the diet with *Bacillus toyoi* or *Bacillus licheniformis* reduced the incidence and severity of diarrhoea and the numbers of enterococci and coliforms in the intestines (Roselli *et al.*, 2005).

Reid and Friendship (2002) have also reviewed findings on this topic and concur with the conclusion that the use of probiotics in piglets has been shown to result in increased efficiency of feed utilization, improved weight gains and reduced incidence of diarrhoea in some studies. However, they concluded that not all probiotic strains are effective in pigs. Other organisms that appear to have some effectiveness include *Enterococcus faecalis, E. faecium* 68, *Bacillus cereus, Bacillus subtilis, B. licheniformis, Lactobacillus acidophilus* and *S. cerevisiae*.

Kyriakis *et al.* (1999) reported a study in which probiotic-containing viable spores of *B. licheniformis* was tested for its efficacy to control post-weaning diarrhoea in piglets raised on a farm with a low health status. Four diets were used, for a 28-day period. One group was given a non-medicated diet, a second group was given the diet supplemented with 10^6 viable spores of *B. toyoi* per g of feed and the other two groups were given the diet supplemented with 10^6 or 10^7 viable spores of *B. licheniformis* per g of feed, respectively. The results showed that all groups supplemented with probiotics exhibited a reduced incidence and severity of diarrhoea. Mortality in all probiotic-supplemented pigs was significantly lower than in the negative control group. Weight gain and efficiency of feed conversion were also better in the treated groups than in the negative control group. The group receiving the high inclusion of *B. licheniformis* performed better than the two other groups receiving probiotics. No enterotoxic strains of *E. coli* were detected on day 22 in pigs fed the diets containing *B. toyoi* or the high inclusion level of *B. licheniformis*.

A current problem with probiotics, at least in North America, appears to be that commercial veterinary probiotic preparations are not accurately represented by label claims (Weese, 2002). In this investigation quantitative bacteriologic culture was performed on eight veterinary probiotics and five human probiotics, and isolates identified by biochemical characteristics. It was found that the label descriptions of organisms and concentrations accurately described the actual contents of only two of

13 products. Five veterinary products did not specifically list their contents. Most products contained low concentrations of viable organisms. Five products did not contain one or more of the stated organisms, and three products contained additional species. Some products contained organisms with no reported probiotic effects; some of these organisms could be pathogens. The authors concluded that quality control appears to be poor for commercial veterinary probiotics.

The results to date suggest that probiotics are not as effective as antibiotics, and that their effectiveness varies due perhaps to the type of diet used. Producers may have to rely, therefore, on the use of feeds containing certain polysaccharides to achieve a beneficial fermentation pattern in the large intestine for the control of enteric disease. Zinc is an important element in fighting infections and is being used together with copper for disease control in conventional pig production. Use of these trace minerals is not approved for that purpose in organic production and producers are advised to use a phytase source in their dietary formulations to help ensure that the maximal amount of dietary zinc is available to the animal and not bound in the dietary ingredients with phytate.

Organic producers using pasture and other outdoor systems are advised to rotate the use of pastures and yards to prevent contamination with external and internal parasites.

Field reports indicate that many herds have internal parasites. As the eggs of these internal parasites (worms) persist in soil for years, rotating pastures and yards may not be totally effective in controlling the problem. Checks on the possibility of parasitism in the herd can be made by post-mortem examination of dead pigs, and by faecal sampling, slaughterhouse checks, and blood tests. Research findings confirm the likelihood of a higher incidence of infection from parasites in organic pigs (Eijck and Borgsteede, 2005). For instance, organically reared pigs had significantly more pathological damage in the liver and lungs, caused mainly by infections with the roundworm *Ascaris suum*. Also, the lungs often showed atelectasis as a result of chronic pneumonia. One of the disadvantages of using diets with partly indigestible carbohydrates is that they can lead to increased parasite infections. For instance, Petkevicius *et al.* (2001) found that diets that led to high numbers of *Oesophagostomum dentatum* were characterized by having high levels of insoluble dietary fibre and a relatively low digestibility. In contrast, a diet composed of highly degradable carbohydrates decreased worm establishment, size and female fecundity. This result suggests that producers should use highly digestible diets during outbreaks of helminth infestation and, where possible, should use liquid whey as a dietary supplement. This product is known to be useful in helping to control ascarid infestations. Grazing management should also be used. Most helminths are strictly host-specific and mixed grazing is known to be useful in helminth control.

Supplementation of the diet with seaweed has been shown to be of value in the control of parasites in pigs, markedly reducing the incidence of liver condemnations from ascarid damage in pigs at slaughter (Jensen, 1972).

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8

Conclusions and Recommendations for the Future

The organic pig industry is small at present but is likely to expand in the future due to a strong demand from consumers for organic foods. It is hoped that the information presented in this book will assist that expansion. At present pig producers lack advisory aids to assist them in developing successful organic systems.

As consumers become more familiar with organic meats it is to be hoped that derogations and permitted exceptions to the regulations will be phased out as soon as possible. Consumers become very upset and distrustful when they discover that some organic foods are not 100% organic in origin. A related issue is that some consumers see the need for assurance that organic food is indeed as described in the label. Research outlined in this book demonstrates that reliable tests to prove that organic pork has indeed been produced according to organic standards may be introduced before too long and should be welcomed by the organic industry.

At present the implementation of regulations and standards is the responsibility of local certifying agencies. The eventual adoption of agreed international regulations and standards will help to ensure uniformity of standards and promote trust in the consumer. The publication of detailed lists of approved feedstuffs by more countries, following the New Zealand example, will also assist the industry worldwide in producing diets that meet the required standards.

As has been pointed out in the text, organic foods have to be produced efficiently so that they compete price-wise with conventional foods. There is evidence that the price the consumer is willing to pay for organic foods is not unlimited. This requires that the diets used in organic pig production – the major cost in production – are formulated correctly to achieve a satisfactory rate of gain and efficiency of feed conversion in the market animals, and satisfactory carcass quality. The acceptance of synthetic vitamins as permitted feed ingredients in organic pig production is a welcome change in the regulations since it aids in achieving these objectives.

It is clear from the existing data that the database of organic feedstuffs composition needs strengthening. Results on nutrient composition from Europe indicate that organic feedstuffs are slightly lower in nutrient content than conventional feedstuffs, but results from North America suggest that both types of feedstuffs are more similar in nutrient content. A more extensive database would help to clarify this issue and would greatly assist organic pig producers in formulating adequate feed mixtures.

A satisfactory rate of gain and efficiency of feed conversion are important in terms of manure output. Pigs growing slowly require much more feed to reach market weight and during this period excrete more manure. As a result there is increased manure loading on the land to absorb all of the excreted nutrients, which may equate to an increase in stocking rate. The diets suggested in the text have been formulated to contain minimal excesses of protein and minerals, and the routine use of a source of phytase supplementation is suggested (if permitted in the local organic regulations) to minimize the impact of excreted minerals on the environment. The acceptance of pure amino acids (AA) as permitted feed ingredients would assist in minimizing the excretion of nitrogen in manure, since it is obvious that some at least of the diets suggested contain more crude protein (CP) than necessary. However, this is not possible at present since pure AA are generally not permitted in organic diets.

It is clear, based on the available evidence, that in comparison with conventional pig production organic pig production has a greater environmental footprint than previously thought. For instance, Kumm (2002) showed that organic production can be more sustainable than conventional production for beef and lamb, but not for pork. The production costs and discharge of nitrogen and greenhouse gases per kg of pork are greater in organic production than in conventional pork production. Organic production also needs more land, which limits its sustainability if land for food production and energy crops is scarce. Other research by Dourmad *et al.* (2014) studied the environmental impacts of 15 pig-farming systems in Denmark, The Netherlands, Spain, France and Germany. Using the conventional system as a baseline it was calculated that the organic system had the following effects: climate change +4%, soil acidification –16%, soil eutrophication +29%, energy utilisation +11% and land occupation +121%. These effects can be explained by the types of organic diets used, which increase nitrogen and phosphate loading on the land and by an increased stocking rate in organic production.

The nutrient requirements of traditional, slow-growing pigs of the type favoured in organic production have not been defined adequately. Therefore the approach taken in this book has been to devise lower-energy diets containing a similar balance of nutrients to that in nutritional standards established for fast-growing hybrid pigs. This seems to be the most logical approach to be taken at present, but research needs to be undertaken to verify this approach and to define the nutritional needs of traditional breeds in sufficient detail. In addition, research needs to be undertaken to establish the contribution of herbage and soil to the vitamin and mineral needs of organic pigs. The evidence at present on this issue is conflicting and the data are not of a standard suitable for acceptance by the scientific community. This research should also be extended to include a study of natural versus synthetic forms of vitamins. The provision that the vitamins used to supplement organic pig diets should preferably be of natural origin conjures up an appealing image, but the practicality of such a proposal needs to be supported by research. The research should also include a study of the bioavailability and stability of natural sources of vitamins.

Another area of research that requires attention is the effect of long lactation periods on the nutritional needs of sows. Scientific data on this topic are lacking. Current standards in conventional production are based on short lactation periods and rapid re-mating. They are not directly applicable in organic production. In addition, animals with access to outdoors expend more energy on physical activity. Until more definitive data are available it is suggested that sow feeding programmes be based on condition scoring of the animals, to ensure that their welfare is maintained during gestation and lactation.

The effects of diet on health need to be investigated in organic production, especially with the prohibition of antibiotics. The research to date indicates that probiotics and prebiotics are not as effective as antibiotics and more effective alternatives have to be identified.

The genetic modification (GM) aspect of feed ingredients needs further consideration. The prohibition in principle on feedstuffs derived by GM technology is understandable but the ramifications of the prohibition need to be examined. As pointed out in the text, a strict interpretation of this provision may ban the use of important vitamins in organic pig diets and lead to deficiencies. Also, products such as protein concentrates from industrial starch production as sources of AA may be considered unacceptable in some countries because of their origin in GM crops. A study to determine the presence or absence of gene fragments derived from GM organisms in these products is needed, to investigate whether these products might qualify as acceptable ingredients for organic production.

A related issue is the possible acceptability of pure AA derived from fermentation sources (lysine, tryptophan and threonine). Several counties are pressing for their acceptability and their current banning is based in part on the premise that they may be derived from GM organisms. Research is needed to determine whether the ban is justified on scientific grounds. The research should examine whether any DNA from the GM organism is associated with the AA product. The project would require that the nature of the construct that is used in the GM organism be known. By searching for a DNA fragment that is part of the expression construct, it would be possible to determine whether the product was transgenic or not. Specific fragments for each of the transgenic events that produced the AA could be detected. Research of this nature could help to establish whether the continued ban on AA derived from fermentation technology can be sustained on the basis of the scientific evidence or whether, given their potential importance as feed ingredients that would allow scarce sources of protein to be utilized more effectively and aid environmental sustainability by minimizing nitrogen excretion in manure, their banning should be overturned.

Another reason given for the current ban on pure AA such as methionine is that they are of synthetic origin, in keeping with the tone of the existing organic regulations that natural sources of nutrients are preferred or mandated over synthetic sources. That position on synthetic versus natural has been shown to be over-simplistic, as is evidenced by the need to approve synthetic vitamins in organic feeds in order not to impair animal welfare. In keeping with the approach suggested above with pure AA derived from fermentation sources, it is suggested that an analysis of the benefits/drawbacks of synthetic AA be conducted, using scientific data. This would help to determine whether the existing ban of synthetic AA is justified scientifically and ethically.

All of the above proposals indicate that nutritionists should be more closely involved in the establishment of future standards for organic pig production.

Another reason for suggesting that the concept of synthetic versus natural be re-examined is that there does not appear to be much evidence that the consumer is particularly concerned over the use of synthetic sources of nutrients in organic feeds. The most important criteria of organic meats for the consumer appear to be their perceived wholesomeness, freshness, freedom from antibiotic and hormone residues, and production using humane methods.

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Index

acid-detergent fibre (ADF) analysis 35
acid detergent lignin (ADL) 227–228
ad libitum feeding 22, 67, 98, 107, 172, 175, 177, 195, 200, 209, 222, 224, 232, 233, 237, 239
agricultural products 2
AgriFood MRL Standard 13
American Association of Feed Control Officials (AAFCO) 61, 91
amino acids (AA) 1, 10, 251–252
anti-nutritional factors
  canola 65–66
  cassava 88–89
  cottonseed 67
  faba 81–82
  field peas 84–85
  groundnuts 72–73
  lentils 85
  linseed 69–70
  lucerne 95
  lupins 87
  potatoes 90
  safflower meal 74
  sesame meal 75
  soybeans 77–78
  sunflower seeds 79
ascorbic acid (vitamin C) 34
Australian National Standard for Organic and Bio-Dynamic Produce 11

Berkshire 206, 212–215
biotin 33, 54, 64, 67, 74, 81, 102, 193
Bísaro pig 205
Brassica campestris 63
Brassica napus 63, 92
breeds and strains of pigs, *see also specific breeds and strains of pigs*
  boars 206
  comparisons 211
  consumer attitudes to organic production 216
  cross-breds 207–209
  diet 213–215
  entire (uncastrated) males 215–216
  exposure to outdoor conditions 209
  genotype 210–213
  meat quality 209
  sows 205–206
  traditional breeds 206
brewer's condensed solubles 53
brewer's dried grains
  nutritional features 52–53
  pig diets 53
brewer's dried yeast 53, 243
brewer's wet grains 53
British Saddlebacks 206

Camborough 206, 209, 210
Canadian Food Inspection Agency (CFIA) 10, 107
Canadian Organic Regulations 215
Canadian Standard for Organic Agriculture 9
canola (*Brassica* spp.) 63–67
  anti-nutritional factors 65
  full-fat canola (canola seed) 66–67
  nutritional features 64–65
  pig diets 65–66
carcass-value marketing system 207
cereal grains and by-products 23, 49–63
  barley 51–53
  brewer's dried grains 52–53
  buckwheat 54
  distiller's dried grains 55–56
  hominy feed 55
  hull-less barley 52
  maize 54–56
  maize gluten feed 55
  maize gluten meal 55
  maize oil 54

cereal grains and by-products (*continued*)
naked (hull-less) oats 56–57
oat groats 57, 124
oats 57
rice 57–58
rice bran 57
rye 58
sorghum 58
spelt 58–59
triticale 59–60
wheat 60–63
wheat bran 61
wheat germ meal 61–62
wheat malt sprouts 53
wheat middlings 62
wheat mill run 62
wheat red dog 62
wheat shorts 62–63
Chinese Shandong 205
choline 33, 64, 72, 77, 81, 96, 102, 103
cobalamin 33
Codex Alimentarius programme 7
cottonseed meal (*Gossypium* spp.) 67–69
anti-nutritional factors 67–68
nutritional features 67
pig diets 68–69
creep-feed 29, 57, 170, 197, 198, 220, 222, 223, 241
cross-breeding 207–209
benefits 208
boar line 208
breeding programme 208
dam genotype 209
genetic selection and 207
and husbandry system 209
objectives 207
for organic production 210
organic standards 208
in sows 207
sustainability 207
crude protein (CP) 3, 21, 22, 34, 35, 49, 170, 184, 251

Danbred 206
diets 170–202
comparison 173
composition and feeding level 224–230
forage-based feeding systems 227–230
forages 224
nutrients from grass 226
restricted-fed animals 224
vitamins and minerals 224–225
and disease prevention 239–245
feed manufacture on-farm 171–192
feed formulas 172–179
feed formulation 180–192
feeding
boars 201–202
breeding gilts and sows 199–201
newborn pigs 197–198
strategy for market pigs 199
weaned pigs 198–199
labels 171
larger farms with grain
for farm use 171
and protein feedstuffs for farm use 171
methods of feeding pigs 195–197
full feeding 195–196
liquid feeding 197
phase (stage) feeding 196
restricted feeding 196
mycotoxins and boar fertility 202
prebiotics 240–243
probiotics 243–245
quality control 192–195
for mycotoxins 194–195
sampling 193–194
tests 192–193
small farms producing no feed ingredients 170–171
use of ingredients, restrictions 5–6
digestibility 19, 22–23, 52, 58, 65, 67–69, 71–73, 75, 77, 78, 80, 84, 85, 88, 90, 92–95, 97, 99, 100, 105, 106, 188, 190, 198, 224, 225, 227, 235, 241, 243, 245
disease prevention 219, 239–240
distiller's dried grains 55–56, 58
dried forages 225, 230, 233
Durocs 22, 82, 206, 209–215, 224

ecological agriculture 1
ecological integrity 1
energy 20–22
ad libitum 22
bulky feeds 22
digestible energy (DE) 20
gross energy (GE) 20
metabolizable energy (ME) 20
net energy (NE) 21
utilization 20
enzymes 104–106
digestive 95
feed 105
essential amino acids (EAA) 2–3

faba (*Vicia faba* L.) 81–83
anti-nutritional factors 81–82
nutritional features 81
pig diets 82–83
fast-growing hybrid pigs 251
fat sources 80–81, 231
effect on pork flavour 234
feed analysis 34–35
ash 34–35
crude protein 35
dry matter (DM) 34
fat 35
moisture (water) 34
non-nitrogenous material 35
organic matter 35
feed formulas 172–179
Denmark 172–173
Finland 173–174
Germany 174–177
organic finisher formulas 179

organic grower formulas 178
organic sow gestation diets 180
organic sow lactation diets 180
organic starter formulas 178
Sweden 177
United Kingdom 177–178
USA 178–179
feed formulation 180–192
feed mixtures 185–189
mixing and further processing 188–189
pelleting 189–192
preparation, weighing, batching and blending 185–188
selection of ingredients 181–185
standards for dietary formulation 183–185
trace mineral premix 182, 183
vitamin and trace mineral 182
vitamin premix 182, 183
feeding 7, 48, 51, 53, 55, 67, 76, 85, 170, 216, 251
boars 201–202
breeding pigs 15
environment 14
newborn pigs 197–198
programmes
diet and disease prevention 239–245
diet composition and feeding level 224–230
genotype 223
housing system 219–223
meat quality 231–239
weaned pigs 198–185
young pigs 2
feedstuffs 2, 3, 15, 20, 24, 32, 44, 45, 64, 73, 90, 100, 157, 171, 178, 195, 236, 250, *see also* nutrient contents of feedstuffs
field peas 83–85
anti-nutritional factors 84
nutritional features 83–84
pig diets 84–85
fish and by-products 100–101
Floury-2 54
folacin (folic acid) 33
Food and Drug Administration (FDA) USA 2, 44, 102
forages and roughages 92–96
cabbage (*Brassica oleracea,* Capitata group) 92–93
crops 228–229
dried 230
grass meal 93–94
lucerne (*Medicago sativa* L., *Medicago* spp.) 94–95
vetch (*Vicia sativa*) 95–96
full feeding 195–196

gene-modified (GM) crops 1
genetic modification (GM) 251–252
Gloucester Old Spot 95, 177, 206, 212
grazing management 6, 245
Green Development and Demonstration Programme 216

Hampshires 177, 206, 210–212
herbage 224, 231, 237, 251
digestibility 94
intake, sows 94
nutrients in 225
holistic production management system 5
hominy feed 55, 119
housing systems 219–209
breeding herds with outdoor management 221
climatic environment on nutritional requirements 221–223
controlled-environment housing 219
European outdoor system 219
and free-range conditions 7
long lactation period 221
outdoor area for pigs 223
Roadnight system 219–221
HSNO Act 44
humane methods 252
husbandry 7, 12, 209
hydrochloric acid 18, 26, 98

ideal protein 23, 24, 89
'ileal digestibilities' 23, 65, 75
ingredients, organic diets
barley and by-products 51–53
brewer's dried grains 52–53
hull-less barley 52
nutritional features 51
pig diets 51–52
brewer's yeast 106–107
buckwheat (*Fagopyrum spp.*) 54
calcium carbonate 49
cereal grains and by-products 49–51
comparison of feedstuffs 45–48
enzymes 104–106
fish and by-products 100–101
forages and roughages 92–96
grain screenings 51
legume seeds and by-products 81–88
maize (*Zea mays*) 54–56
microorganisms 106
milk and milk products 97–100
mineral sources 101–102
nutrient contents of feedstuffs 157
oats (*Avena sativa*) 56–57
oilseeds and by-products 63–81
plants and plant by-products 96–97
rice (*Oryza sativa*) 57–58
rye (*Secale cereale*) 58
sorghum (Sorghum vulgare) 58
spelt (*Triticum aestivum* var. *spelta*) 58–59
triticale (*Triticale hexaploide, Triticale tetraploide*) 59–60
tuber roots and by-products 88–92
vitamin sources 102–103
wheat (*Triticum aestivum*) 60–63
International Federation of Organic Agriculture Movements (IFOAM) 7, 9–13, 174
International Organization for Standardization (ISO) 8

international standards 6–15
Africa 11
Asia
China 13–14
India 14
Japan 14
Republic of Korea 14
Australasia
Australia 11–12
New Zealand 12
Europe 8–9
impact 14–15
Latin America
Argentina 10
Brazil 11
Chile 11
North America
Canada 9–10
Mexico 10
USA 9
other countries 14
Russia 14

Japanese Agricultural Standards (JAS) 14

Kenya Organic Agriculture Network (KOAN) 11
Krškopolje or Blackbelted pig 205

Landrace 68, 75, 174, 177, 205–212, 220, 222, 224
Large White, *see* Yorkshire
legume haylage 230
legume seeds and by-products 81–88
faba (*Vicia faba* L.) 81–83
field peas 83–85
lentils (*Lens culinaris*) 85
lupins 85–88
linseed (*Linum usitatissimum*) 69–71
anti-nutritional factors 69–70
flaxseed 70–71
nutritional features 69
pig diets 70
liquid feeding 96–97, 180, 197
livestock production 5–8
lucerne (*Medicago sativa* L., *Medicago* spp.) 94–95
anti-nutritional factors 95
nutritional features 94–95
pig diets 95
silage 95
lupins 65, 85–88, 92, 172–176, 224
anti-nutritional factors 87
nutritional features 86–87
pig diets 87–88
sainfoin (*Onobrychis viciifolia*) 88

macro minerals 24, 37, 69
maize gluten feed 55
maize gluten meal 55
maize silage 227, 230
malt cleanings 53
malt sprouts 53
meat quality 209, 231–239
analysis 212
comparisons 212
feed on pork flavour 231–236
dietary protein and energy levels 231–232
fat source 234–235
grain source 232–234
miscellaneous sources 235–236
protein source 234
forage-based diets 237–239
organic feeding on pork 236–237
Mediterranean silvopastoral system 219
Meishan 212
micronization process 52
milk and milk products 97–100
buttermilk 98
by-products in liquid form 97–99
dried milk products 99–100
skimmed (separated) milk 97–98
whey 98–99
minerals 24–27
calcium and phosphorus 25–26
macro minerals 24
magnesium 27
required by pigs 25
sodium, potassium and chloride 26–27
sulphur 27
trace 27–30
cobalt 27–28
copper 28
iodine 28
iron 28–29
manganese 29
selenium 29–30
zinc 30
Ministry of Agriculture, Food and Rural Affairs (MAFRA) 14
mycotoxins
and boar fertility 202
contamination 195
geographic occurrence 194
on pigs 194–195
quality control for 194–195
residues in animal products 195
routine testing 195

naked (hull-less) oats 56–57
National Competent Authority 9
National Organic Agricultural Movement of Uganda (NOGAMU) 11
National Organic Program (NOP) 9–10
National Organic Standards (NOS) 9
National Programme for Organic Production (NPOP) 14
near infra-red reflectance spectroscopy (NIRS) 35, 181
neutral-detergent solubles (NDS) 35
Newsham 206
niacin (nicotinic acid) 33, 50, 54, 64, 72, 81, 96
non-synthetic substances 2

nutrient contents of feedstuffs 157
barley 107
cabbage 108
canola meal expeller 110
canola seed cooked 109–110
cassava 111
cottonseed meal expeller 112
distiller's grains with solubles, dried 113
faba beans 114
flaxseed (linseed) meal expeller 116
grass meal dehydrated 117
herring meal 118
hominy feed 119
inclusion rates 156
kelp meal 120
lucerne (alfalfa) dehydrated 121
lucerne (alfalfa) sun-cured 122
lupinseed meal sweet white 123
maize yellow 124
Menhaden fishmeal 125
milk skimmed dehydrated 127
milk skimmed fluid 126
molasses
cane 128
sugarbeet 129
oat groats 131
oats 130
peanut (groundnut) meal expeller 132
peas, field 133
potato protein concentrate 135
potatoes, cooked 134
rice bran 136
rye 137
sainfoin seed 138
dehulled 139
sesame meal expeller 140
sorghum (milo) 141
soybean meal expeller 143
soybean meal extruded-expelled 144
soybeans, cooked 142
sugarbeet pulp, dried 145
sunflower meal dehulled expeller 146
swedes 147
triticale 148
wheat 149
wheat middlings 150
wheat shorts 151
whey sweet dehydrated 152
whey sweet fluid 153
white fishmeal 154
yeast, brewer's dehydrated 155
Nutrient Requirements of Swine 2012 35
nutrition, elements of pig
derivation of standards 37
digestibility 19
digestion and absorption 17–19
digestive system 18
jejunum and ileum 19
large intestine 19
mouth 17
small intestine 18–19
stomach 17–19
feed analysis 34–35
requirements 20–34
of breeding pigs 38–39
energy 20–22
of growing-finishing pigs 40–41
minerals 24–27
protein 22–24
publications on 35–37
trace minerals 27–30
vitamins 30–34
water 34

oilseeds and by-products 63–81
canola (*Brassica* spp.) 63–67
cottonseed meal (*Gossypium* spp.) 67–69
fat sources 80–81
groundnuts (*Arachis hypogaea* L.) 72–73
linseed (*Linum usitatissimum*) 69–71
mustard 71–72
safflower meal (*Carthamus tinctorius*) 73–75
sesame meal (*Sesamum indicum*) 75–76
soybeans (*Glycine max*) and soybean products 76–79
sunflower seeds and meal (*Helianthus annus*) 79–80
on-farm diets 92, 174–176
Opaque-2 54
organic agriculture 1, 10, 11, 14
Food Standards Programme 5
principles 1
organic farming 1, 170, 227
Danish regulations 9
standards 6
Organic Foods and Development Certification Center (OFDC) 13
organic grower formulas 178
organic legislation
EU 8–9
USA 9
organic pig production
certification and verification 5
in Denmark 2
non-GM crops 63, 64
organic pork 1, 10, 174, 177, 215, 237–238, 250
Organic Production and Handling System Plan 9
organic production system 2
organic standards 6, *see also* international standards
aim 6
Codex Alimentarius 5
IFOAM 7
organic starter formulas 178

pantothenic acid 33, 50, 64, 67, 72, 81, 102
pastures 15, 229–231, 239, 245
pelleting 26, 51, 58, 89, 96, 189–192
advantages 190
bioavailability of nutrients 191
ingredients 191
optimum moisture content 189
pellet binders 191–192
vitamins loss, feed processing 191

phase (or stage) feeding 196
pig-farming systems, Denmark 251
pig-rearing systems, Aberdeenshire 220
plants and plant by-products 96–97
 molasses 96
 seaweeds 96–97
potatoes (*Solanum tuberosum*) 88–90
 anti-nutritional factors 89
 by-products 90–92
  dehydrated potato waste 91
  potato protein concentrate 92
  potato pulp 91
  steamed peelings 91
  waste potato chips 91
 nutritional features 88–89
 pig diets 90
premix
 trace mineral 182, 183
 vitamin 182, 183
proximate composition 192
pyridoxine 33, 67, 70, 72, 102

Quebec standard 10

restricted feeding 20, 22, 52, 183, 189, 196, 201, 224, 233, 239
riboflavin 33–34, 41, 64, 74, 81, 102, 225
'Roadnight' pig-rearing system 219–221

Saddleback breed 206
safflower meal (*Carthamus tinctorius*) 73–75
 anti-nutritional factors 74
 nutritional features 74
 pig diets 74–75
Servicio Nacional de Salud (SENASA) 10
silage and haylage 230
slow-growing breeds 2, 177, 251
sows
 feeding programme for 200–201
 feeding strategy 201
soybeans (*Glycine max*) and soybean products 76–79
 anti-nutritional factors 77–78
 full-fat soybeans 78–79
 nutritional features 77
 pig diets 78
 soy protein isolates 79
spent grains 52
split-sex feeding 199
Spotted breed 206, 208
synthetic animal drugs 6
synthetic substances 2

Tamworths 101, 206, 212–215
Tanzanian Organic Agriculture Movement (TOAM) 11
thiamin 31, 34, 50, 72, 81, 102
tuber roots and by-products 88–92
 cassava 88–89
 potato by-products 90–92
 potatoes (*Solanum tuberosum*) 88–90
 swedes (*Brassica napus*) 92

United Kingdom Register of Organic Food Standards (UKROFS) 9
US National Genetic Evaluation Program 206

vitamins 30–34
 classifications 30–31
 definition 30
 fat-soluble and water-soluble 31
 international unit (IU) 32
 required by pigs 32
 response to signs of vitamin deficiency 34
 vitamin A 31
 vitamins D, E and K 32–33
 water-soluble (B) vitamins 33

wheat (*Triticum aestivum*) 60–63
 milling by-products 61–63
  wheat bran 61
  wheat flour 61
  wheat germ meal 61–62
  wheat middlings 62
  wheat mill run 62
  wheat red dog 62
  wheat shorts 62–63
 nutritional features 60–61
 pig diets 61

Yorkshire (Large White) 75, 177, 201, 206–212

Nutrition and Feeding of Organic Pigs, 2nd Edition

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