BRIEFING PAPER

Nutritional aspects of cereals

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Summary

Cereals are the edible seeds or grains of the grass family, Gramineae. A number of cereals are grown in different countries, including rye, oats, barley, maize, triticale, millet and sorghum. On a worldwide basis, wheat and rice are the most important crops, accounting for over 50% of the world's cereal production. All of the cereals share some structural similarities and consist of an embryo (or germ), which contains the genetic material for a new plant, and an endosperm, which is packed with starch grains.

After harvest, correct storage of the grain is important to prevent mould spoilage, pest infestation and grain germination. If dry grains are held for only a few months, minimum nutritional changes will take place, but if the grains are held with a higher amount of moisture, the grain quality can deteriorate because of starch degradation by grain and microbial amylases (enzymes). Milling is the main process associated with cereals, although a range of other techniques are also used to produce a variety of products. Slightly different milling processes are used for the various grains, but the process can generally be described as grinding, sifting, separation and regrinding. The final nutrient content of a cereal after milling will depend on the extent to which the outer bran and aleurone layers are removed, as this is where the fibre, vitamins and minerals tend to be concentrated. There is potential for contamination of cereals and cereal products by pests, mycotoxins, rusts and smuts. Recently, acrylamide (described as a probable carcinogen) has been found in starchy baked foods. No link between acrylamide levels in food and cancer risk has been established and based on the evidence to date, the UK Food Standards Agency has advised the public not to change their diet or cooking methods. However, the Scientific Committee on Food of the European Union (EU) has endorsed recommendations made by Food and Agriculture Organisation/World Health Organization which include researching the possibility of reducing levels of acrylamide in food by changes in formulation and processing.

Cereals have a long history of use by humans. Cereals are staple foods, and are important sources of nutrients in both developed and developing countries. Cereals and cereal products are an important source of energy, carbohydrate, protein and fibre, as well as containing a range of micronutrients such as vitamin E, some of the B vitamins, magnesium and zinc. In the UK, because of the mandatory fortification of some cereal products (*e.g.* white flour and therefore white bread) and the voluntary fortification of others (*e.g.* breakfast cereals), cereals also contribute significant amounts of calcium and iron. Cereals and cereal products may also contain a range of bioactive substances and there is growing interest in the potential health benefits these substances may provide. Further research is required in this area, including identification of other substances within cereals and their bioavailability.

There is evidence to suggest that regular consumption of cereals, specifically wholegrains, may have a role in the prevention of chronic diseases such as coronary

heart disease, diabetes and colorectal cancer. The exact mechanisms by which cereals convey beneficial effects on health are not clear. It is likely that a number of factors may be involved, *e.g.* their micronutrient content, their fibre content and/or their glycaemic index. As there may be a number of positive health effects associated with eating wholegrain cereals, encouraging their consumption seems a prudent public health approach. To increase consumption of wholegrain foods, it may be useful to have a quantitative recommendation. Additionally, a wider range of wholegrain foods that are quick and easy to prepare would help people increase their consumption of these foods. As cereal products currently contribute a considerable proportion of the sodium intake of the UK population, manufacturers need to continue to reduce the sodium content of foods such as breakfast cereals and breads where possible.

Nutrition labelling is currently not mandatory in the UK, although many manufacturers provide information voluntarily. The fibre content of most UK foods is still measured using the Englyst method rather than the American Association of Analytical Chemists (AOAC) method used by other EU countries and the USA. However, UK recommendations for fibre intake currently relate to fibre measured by the Englyst method and not the AOAC method, and hence need revisions. EU changes to labelling regulations will see the labelling of common foods and ingredients causing allergic reactions, including cereals containing gluten and products derived from these foods. The introduction of EU legislation covering health claims may help consumers identify foods with proven health benefits.

Several misconceptions exist among the public with regard to cereals and cereal products. Firstly, many more people believe they have a food intolerance or allergy to these foods than evidence would suggest and, secondly, cereals are seen by some as 'fattening'. The public should not be encouraged to cut out whole food groups unnecessarily and, as cereals and cereal products provide a range of macro- and micronutrients and fibre, eliminating these foods without appropriate support and advice from a registered dietitian or other health professional could lead to problems in the long term.

In the future it is possible that white flour in the UK may be fortified with folic acid (the synthetic form of the B vitamin folate) to decrease the incidence of neural tube defects during pregnancy. Such a move could also be of benefit for heart health, as poor folate status is associated with high homocysteine levels, an emerging risk factor for cardiovascular disease. However, high intakes of folic acid can mask vitamin B_{12} deficiency, a condition that occurs more frequently with age and has serious neurological symptoms affecting the peripheral nervous system.

Manipulating the expression of native genes can increase the disease resistance of cereal crops. Novel genes may also be used for this purpose, as well as for developing cereals with resistance to herbicides, and cereals with improved nutritional properties (*e.g.* increased levels of iron in cereals and of beta-carotene in rice). The long-term consequences and consumer acceptability of such advances must be considered and consumer choice maintained. There is a continual growth in the knowledge of the interactions between human genes and nutrients, and in the future it may be possible to target specific nutrition messages to people with specific genetic profiles.

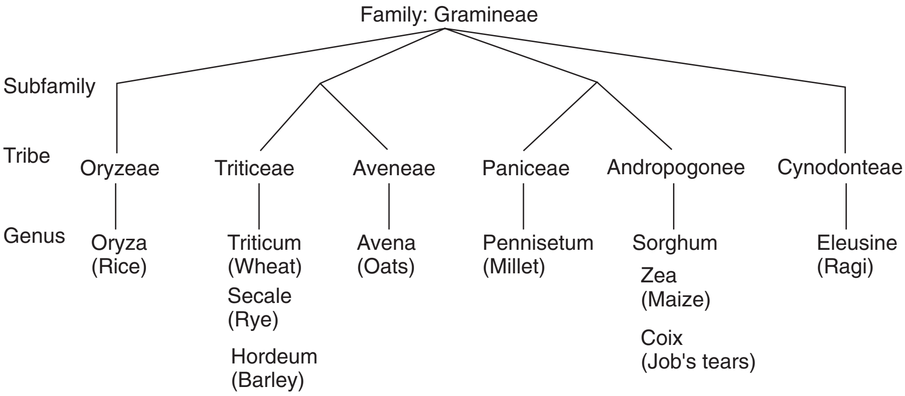

Figure 1 Taxonomy of the Gramineae family (source: Shewry *et al.* 1992).

1 Introduction

Cereals can be defined as a grain or edible seed of the grass family, Gramineae (see Fig. 1) (Bender & Bender 1999). Cereals are grown for their highly nutritious edible seeds, which are often referred to as grains. Some cereals have been staple foods both directly for human consumption and indirectly via livestock feed since the beginning of civilisation (BNF 1994). Cereals are the most important sources of food (FAO 2002), and cereal-based foods are a major source of energy, protein, B vitamins and minerals for the world population. Generally, cereals are cheap to produce, are easily stored and transported, and do not deteriorate readily if kept dry.

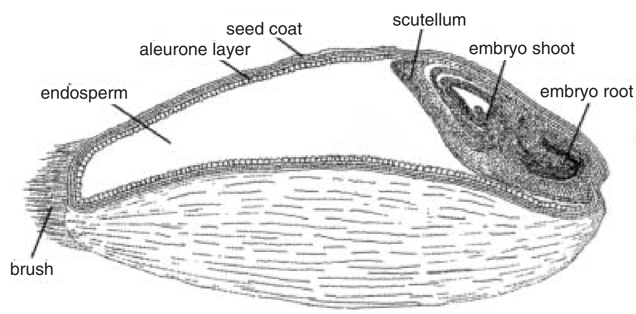

Figure 2 General structure of a grain (source: *Wheat: The Big Picture* (Dr Gary Barker, webmaster: Gary.Barker@Bristol.ac.uk).

1.1 General structure of grains (Fig. 2)

Grains develop from flowers or florets and, although the structures of the various cereal grains are different, there are some typical features. The *embryo* (or germ) is a thin-walled structure, containing the new plant. It is separated by the *scutellum* (which is involved in mobilisation of food reserves of the grain during germination) from the main part of the grain, the *endosperm*. The endosperm consists of thin-walled cells, packed with starch grains. If the cereal grain germinates, the seedling uses the nutrients provided by the endosperm until the development of green leaves that allow photosynthesis to begin (FAO 1991; Kent & Evers 1994). The endosperm is surrounded by the *aleurone*, consisting of one or three cell layers (wheat, rye, oats, maize and sorghum have one; rice and barley three). The outer layers of the grain are the pericarp (derived from the ovary of the flower) which surround the *seed coat* (the testa). The outer thick-walled structures form the bran.

1.2 Wheat

Wheat is a major cereal crop in many parts of the world. It belongs to the Triticum family, of which there are many thousands of species (Kent & Evers 1994), with *T. aestivum* subspecies Vulgare and the hard wheat *T. durum* being the most important commercially (Macrae *et al.* 1993). Wheat is grown as both a winter and a spring cereal and, owing to the number of species and varieties and their adaptability, it is grown in many countries around the world. The great wheat-producing countries of the world include the USA, China and Russia; extensive wheat growing occurs in India, Pakistan, the European Union (EU), Canada, Argentina and Australia. It is estimated that 556.4 million tonnes of wheat will have been produced in 2003, accounting for 30% of the world's cereal production (FAO 2003).

An ear or spike of grain is made up of spikelets (see Fig. 3a). The wheat grain is enclosed between the lemma and the palea of each spikelet (see Fig. 3b). The grain may be elliptical, oval or ovate in shape and have short or long brush hairs. Most cultivated varieties of wheat have fusiform spikes, may be awned (bearded) or awnless, and are easily threshed.

Wheat is generally not classed by variety. Instead classes are used, based on the time of year the wheat is grown and the milling and baking quality of the flour

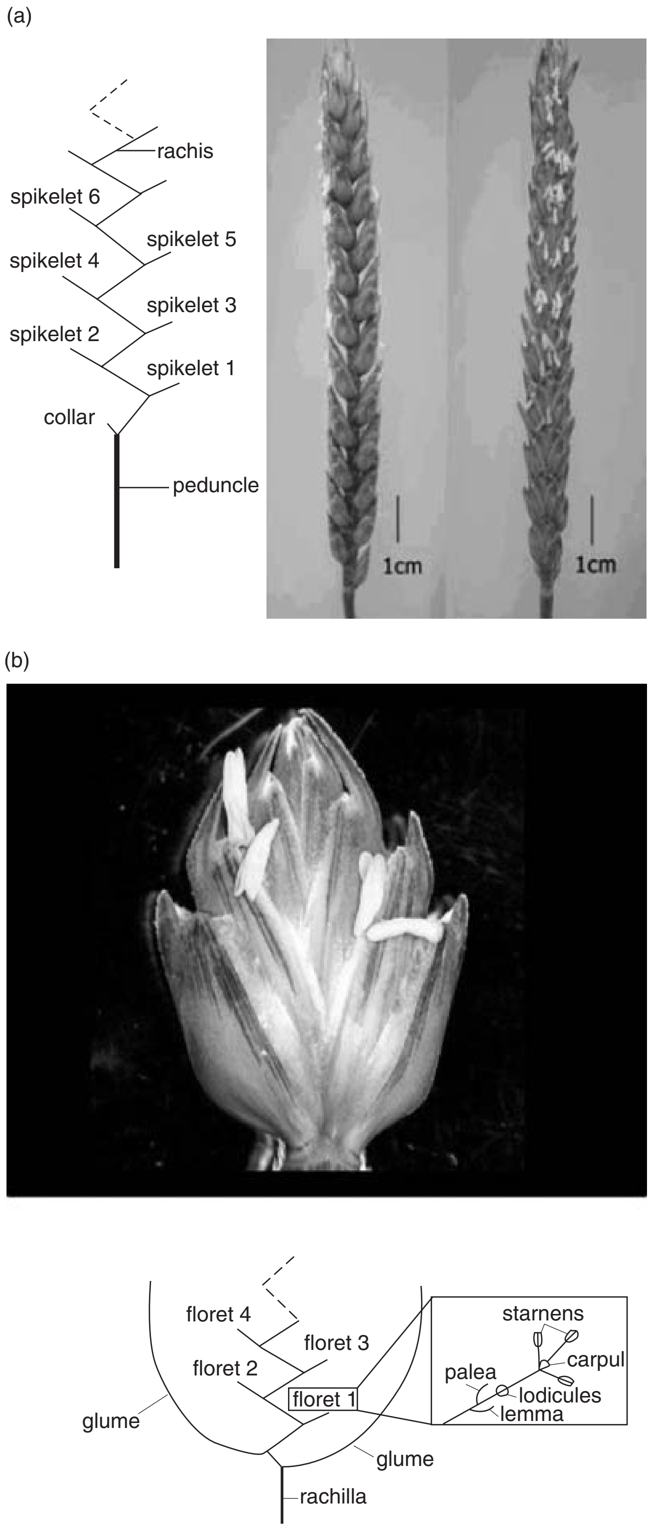

Figure 3 (a) Ear of wheat (b) Wheat grain. (source: Wheat: The Big Picture (Dr Gary Barker, webmaster. Gary.Barker@Bristol.ac.uk).

produced. Within each class there is a group of different varieties of wheat with similar characteristics. Most of the wheat produced is used for human consumption and because of its unique properties, a large range of ingredients and foods are produced, including wheat germ, spelt (a coarse type of wheat), couscous, cracked wheat or bulgur and wheat starch.

1.3 Rice

Rice is an important crop, forming a staple food for many of the world's population, especially those living in Asia. Rice is produced mainly for use as human food, including breakfast cereals, and in Japan it is also used to brew saké (Kent & Evers 1994). There is a huge number of rice varieties (~100 000) but only a few are grown widely (*e.g.* varieties of the improved semi-dwarf plant type with erect leaves). Cereal production within the European Union is shown in Table 2.

The rice grain consists of an outer protective coating (referred to as the hull or husk) and the edible rice caryopsis. Brown rice consists of the outer layers of pericarp (which contains pigment), seed coat, the embryo and the endosperm (comprising the aleurone layer which encloses the embryo, subaleurone layer and the starchy or inner endosperm).

Wild rice is unrelated to rice. It is the grain of a North American plant, *Zizania aquatica*, and, as it is difficult to harvest, is more expensive than other grains. It has a higher protein content than rice (Bender & Bender 1999).

1.4 Maize

Zea mays L., also referred to as corn, originated in the Western Hemisphere (Fast & Caldwell 2000). It is a cheap form of starch and is a major energy source for animal feed (Macrae *et al.* 1993). Although there are hundreds of different varieties, the four main categories of commercial importance are:

(1) dent maize (identified by the dent in the crown of the kernel);
(2) flint maize (hard, round kernels);
(3) sweet corn (a dent-type maize);
(4) popcorn (flint-type maize which expands when heated).

The maize kernel (the reproductive seed of the plant) has four main parts – the germ, the endosperm, the pericarp and the tip cap. Production in the USA exceeds that in any other country (Fast & Caldwell 2000) and much research has been done in the USA on the maize genome (see section 4.2 for more on genetic modification).

1.5 Barley

Barley is a resilient plant, tolerant of a range of conditions, which may have been cultivated since 15 000 BC (Fast & Caldwell 2000). Cultivated barley, *Hordeum vulgare*, is mainly grown for animal feed, especially for pigs, for malting and brewing in the manufacture of beer and for distilling in whisky manufacture. A small amount of barley is used for food. Pearled barley is eaten in soups and stews in the UK and in the Far and Middle East; barley is also used in bread (as flour) and ground as porridge in some countries (Kent & Evers 1994).

The barley head or spike is made up of spikelets, which are attached to the rachis in an alternating pattern. The outer layers of the barley kernel consist of a husk, completely covering the grain; the pericarp (to which the husk is tightly joined in most species); the testa or seed coat and the aleurone.

1.6 Oats

Oats can grow well on poor soil and in cool, moist climates and have mainly been grown for animal feed. A small proportion is produced for human consumption – oatmeal for porridge and oatcakes, rolled oats for porridge, and oat flour for baby foods and for ready-to-eat (RTE) breakfast cereals (Kent & Evers 1994). Oats are also used in a range of non-food uses, including cosmetics and adhesives (Macrae *et al.* 1993).

There are several different species, with the common spring or white oat (*A. sativa* L.) being the most important cultivated form. *A. byzantina* is a red-oat type adapted to warmer climates where it is grown as a winter oat. An oat spikelet consists of oat kernels. Each kernel is enclosed by a hull (made up of two layers – a lemma and palea) which is only loosely attached to the groat. The groat, which makes up 65–85% of the oat kernel, is enveloped by bran layers (pericarp, seed coat and aleurone cells).

1.7 Rye

Rye is a hardy plant and is generally grown in cool temperature zones, where other cereals can not be grown. Rye can also grow at high altitudes and in semi-arid areas. It is grown as a winter crop, being sown in early autumn and harvested in early summer. The plant may vary in height from 30 cm to more than 2 m. It is a major crop in Russia, Poland, Germany and the Scandinavian countries, where it is the major bread grain. Rye is also used to produce crispbread and alcohol, and it is used as animal feed (Kent & Evers 1994).

The grain is covered with a *glume* (husk), which is normally bearded, and grains are arranged in an alternating pattern along the rachis. The grain is thinner and more elongated than wheat; it is normally greyish-yellow in colour and varies in size from 1.5 mm to 3.5 mm. The grain consists of the starchy endosperm (~86% of the grain), the pericarp and the testa (jointly referred to as the bran and accounting for 10% of the grain), with the remainder consisting of the germ (the embryo and scutellum).

1.8 Millet

Millet refers to a number of different species, all of which are small-grained, annual cereal grasses (Macrae *et al.* 1993; Bender & Bender 1999). The most important type is pearl millet. A number of minor millets exist, including finger (or ragi), proso and foxtail but as these account for less than 1% of the grains produced for human consumption, they are less important in terms of world food production. However, these crops are important in certain locations in Africa and Asia, where major cereals can not be relied on to provide sustainable yields (FAO 1995). Climatic and soil requirements, length of growing period, grain consistency, size and taste differ depending on the species.

Job's tears (Coix lachryma-jobi) is a type of millet wild grass, related to maize. It grows wild in parts of Africa and Asia, where its seeds (adlay) are eaten (Bender & Bender 1999).

1.9 Sorghum

Sorghum (*Sorghum bicolor* L. Moench) is a warm season crop, intolerant of low temperatures but fairly resistant to serious pests and diseases. It is known by a variety of names (such as great millet and guinea corn in West Africa, kafir corn in South Africa, jowar in India and kaoliang in China) and is a staple food in many parts of Africa, Asia, and parts of the Middle East. Most of the sorghum produced in North and Central America, South America and Oceania is used for animal feed (FAO 1995).

The grain consists of a naked caryopsis, made up of a pericarp, endosperm and germ. Although there is a huge range of physical diversity, sorghums are classed into one of four groups – (1) grain sorghum; (2) forage sorghum; (3) grass sorghum; or (4) Sudan sorghums and broomcorn (Macrae *et al.* 1993). Sorghums are grouped using the following characteristics:

- the colour of the pericarp (white, yellow or red);
- presence/absence of pigmented testa (with/without tannins);

- pericarp thickness;
- endosperm colour (white, heteroyellow or yellow);
- endosperm type (normal, heterowaxy or waxy).

1.10 Triticale

Triticale (full name Triticosecale) was the first cereal produced by man by crossing wheat and rye. It has the winter hardiness of rye and the baking properties of wheat (Bender & Bender 1999). It is, however, susceptible to diseases which attack wheat and rye (Macrae *et al*. 1993). Triticale is used mainly as a feed crop but it can be milled into flour and used to make bread, although adjustments are needed in recipe formulation because it does not have the same gluten content as wheat (Kent & Evers 1994).

1.11 Other grains

In addition to the cereals outlined above, there are several others which, although not important on a global level, may have an important role in certain parts of the world. For example, buckwheat (also known as Saracen corn) is produced from the plant *Fagopyrum esculentum* and is eaten as a cooked grain, porridge or baked into pancakes. From the South American plant *Chenopodium album* comes the grain quinoa, which is used in Chile and Peru to make bread (Bender & Bender 1999).

1.12 Key points

• There are many different types of cereals grown worldwide, each sharing some structural similarities.

• Cereals are the grain or edible seed of plants belonging to the grass family and are very important nutritionally.

• Cereals consist of an embryo (or germ) which contains the genetic material for a new plant. The main part of the grain, is the endosperm, packed with starch grains. If the cereal grain germinates, the seedling uses the nutrients provided by the endosperm until the development of green leaves.

2 Technical aspects of cereals

Although various cereals are grown in different countries depending on climatic conditions, wheat and rice are the most important cereals worldwide. Cereals are grown for export as well as for domestic use and a number of different processes are used. These processes can affect the nutritional and technical properties of the end product.

Table 1 Forecasts for cereal production in 2003 (million tonnes)

Area	Wheat	Rice (paddy)	Coarse grains (all other grains)
Asia	245.6	541.0	211.4
Africa	20.5	18.0	84.9
Central America	3.0	2.4	29.1
South America	22.0	19.5	76.0
North America	83.3	8.9	302.3
Europe	160.0	3.0	198.6
Oceania	22.0	0.4	10.4
World	556.4	396	912.8

Source: FAO 2003.

Table 2 Useable cereal produced and human consumption of cereals within the European Union for 2000/2001 (all figures are in 000 tonnes)

Country	Useable production 2000/2001	Human consumption 2000/2001
Belgium	2 246	1112
Denmark	9 412	595
Germany	45 219	8033
Greece	Data not available	Data not available
Spain	23 475	4110
France	Data not available	Data not available
Ireland	2 383	472
Italy	19 390	9822
Luxembourg	154	41
The Netherlands	Data not available	Data not available
Austria	4 498	849
Portugal	1 484	1292
Finland	4 089	538
Sweden	5 669	841
The UK	23 991	7409

Source: Eurostat 2002.

2.1 Cereal production

Cereals are grown in a range of countries (Table 1). The forecast for the world's cereal production in 2003 is 1865 million tonnes, 30% as wheat and 21% as milled rice. Over 50% of the world's cereal is produced in developing countries (FAO 2003).

The total UK 2003 cereal harvest was an estimated 22.3 million tonnes, with wheat and barley accounting for about 66% and 30%, respectively, and oats accounting for about 3.5% of the total cereal production (DEFRA & National Statistics 2003) (Table 2).

2.2 Storage

After harvest, grains may either be temporarily stored on the farm before being taken to a collection centre, or the grains may go directly to a collecting centre. Grains are then transported to larger storage facilities called country elevators, which are filled with grain by rolling belts.

Although methods for maintaining the quality of cereal grains have been in practice since ancient times, deterioration is seen even in countries with advanced technology (Chelowski 1991). Storage is associated with a range of hazards. Mould spoilage, pest infestations and grain germination (which can occur if sufficient moisture is present, *e.g.* condensation can be produced in metallic bins) are the main problems (see section 2.4 about food safety issues for further information on these topics). Good storage is vital to minimise post-harvest losses and although moisture content is the most important property affecting stability of the grain during storage (Chelowski 1991), temperature and duration of storage are also important factors (Richard-Molard 2003).

An important step prior to storage is drying, to remove excess water from the grain (Table 3). A range of different types of driers may be used. High-temperature driers are capable of drying large quantities of grain quickly but may also affect the grain if not used correctly, *e.g.* thermal denaturing of the cereal's protein may affect the properties of the final product. However, this method has the advantage of destroying insects. Natural drying methods have also been used, *e.g.* drying corncobs using wind and solar driers. Cereals can also be stored with higher water contents than usual in modified atmospheres, but this is only appropriate when the end product is not required to have special properties (*e.g.* to possess functional properties of bread). Examples of modified atmosphere storage include underground storage and silos flushed with nitrogen. These storage methods have the added advantage of killing insects.

Table 3 Codex standards for maximum moisture content (%) of selected cereals

Grain	Maximum moisture content*	Codex Alimentarius Standard†
Maize	15.5%	Codex Standard 153-1995
Oats	14.0%	Codex Standard 201-1995
Rice	15.5%	Codex Standard 198-1995
Sorghum	14.5%	Codex Standard 172-1989a (Revision 1-1995)
Wheat	14.5%	Codex Standard 199-1995
Durum wheat	14.5%	
Whole and decorticated pearl millet grains	13.0%	Codex Standard 169-1989b (Revision 1-1995)

*Lower moisture limits required for certain destinations in relation to climate, duration of transport and storage. †Codex Alimentarius 1989a, 1989b, 1995a, 1995b, 1995c, 1995d.

During storage there may be some nutritional changes to the cereals, although for dry grains these changes will be small even over a period of several months. If grains are stored with a higher than ideal moisture content, grain and microbial amylases may begin to breakdown the starch, leading to a deterioration of grain quality (Macrae *et al.* 1993). Unsaturated acids can be oxidised to produce off-flavours and rancid odours (Macrae *et al.* 1993). There is little change in protein content, and Jood & Kapoor (1994) found little change in the vitamin content of wheat, maize and sorghum grains during storage (up to 4 months) in insect-free conditions. Rice may be aged for 3–4 months to improve the milling yield and to make the milled rice expand more during cooking (Macrae *et al.* 1993).

2.3 Processing

Cereals typically undergo a range of processes to produce a variety of different products, including non-food products. Milling is the main process associated with cereals, especially the bread cereals wheat and rye. Slightly different milling techniques are used for the various cereals (see below) and a range of other processes may also be used (*e.g.* extrusion and fermentation) in the production of cereal products. As well as having technical consequences, processing also changes the nutritional content of cereals.

2.3.1 Milling

The process of milling can basically be described as grinding, sifting, separation and regrinding. These steps are repeated to extract a particular part of the grain, the endosperm. Before milling begins, the cereal grains are cleaned. Most modern equipment uses differences in size, shape, colour, solubility, specific weight and response to magnetic force to separate foreign material from the grains. Prior to grinding, water may be added to the cereal, which is allowed to rest before milling (*tempering*). This allows absorption of water by the grains, toughening the pericarp and germ so they do not splinter during milling. If heat is also applied during tempering (to mellow the endosperm and make it easier to grind), then the process is referred to as *conditioning* (Hoseney 1994). To ensure production of a uniform product, different grains may be blended prior to milling and this is referred to as *gristing* (Fig. 4).

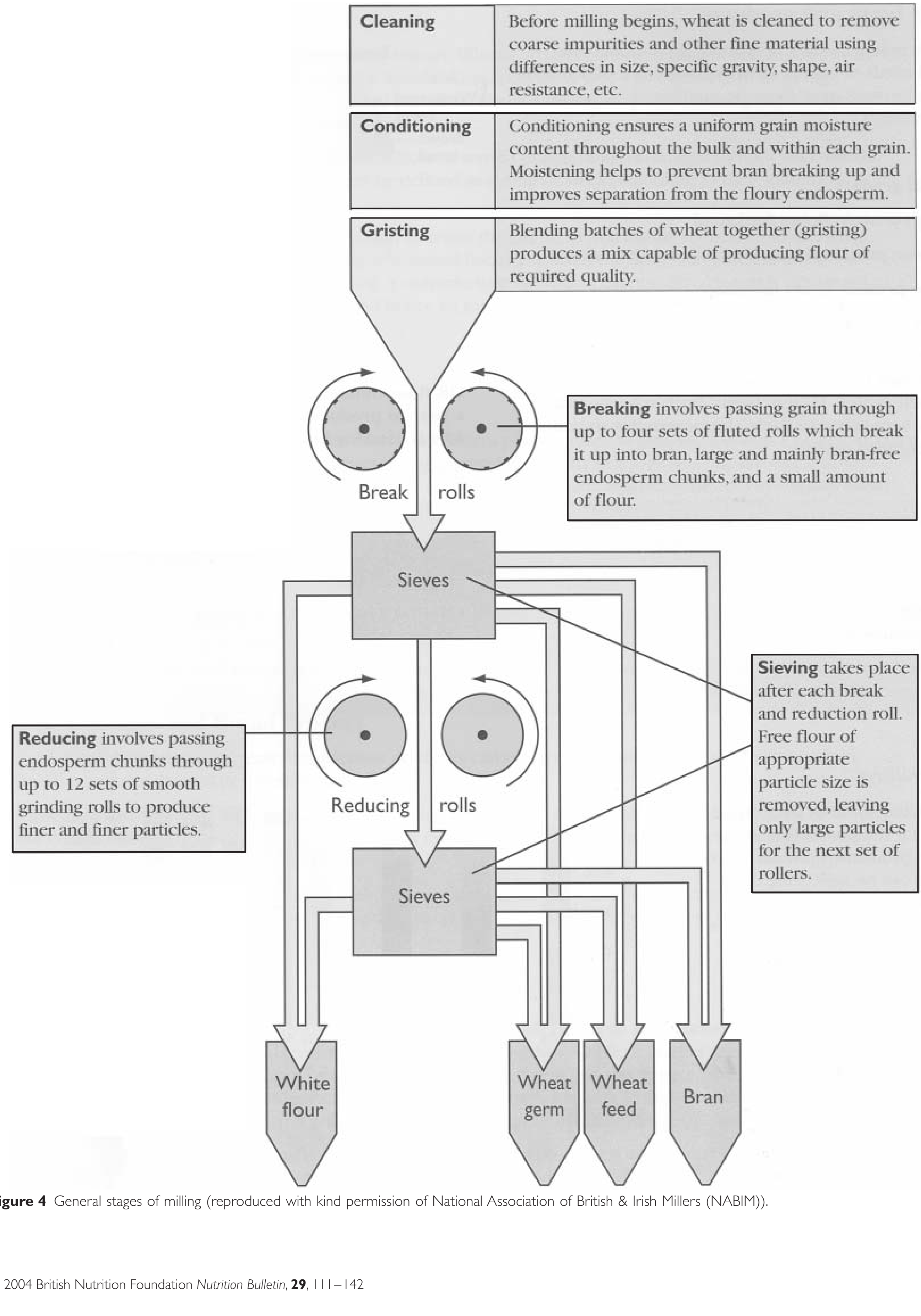

Figure 4 General stages of milling (reproduced with kind permission of National Association of British & Irish Millers (NABIM)).

In ancient times, milling was performed using stones to crush the grain. Now grains are ground between two rotating rollers. The first grinding stage through a groove (referred to as breaking) opens the kernel and scrapes off the endosperm. Then smooth 'sizing' and 'reduction' rollers decrease the endosperm granules to a fine flour. After each stage of grinding, material is sent to a sifting machine, where rotating sieves with differently sized apertures separate particles of similar size. These particles are then purified using air currents to separate out endosperm and bran.

Milling rye Although this is similar to milling wheat, rye is more prone to ergot (see section 2.4) so great care is taken to remove this fungus during cleaning. Rye is also tempered for a shorter period of time (6 h) because rye kernels are softer than wheat kernels (Hoseney 1994).

Milling sorghum and millets These cereals are mainly processed by traditional methods, using a hand-operated wooden pestle and mortar. Generally the grains are pounded and the husk removed by winnowing or floatation. The grains are pounded further before sieving (to remove coarse material which is pounded again) to produce flour and meal.

Milling rice Whole (paddy) rice is dehulled by a rubber-roll sheller to produce brown rice and coarse bran (from the husk). Brown rice can be further processed to remove the bran and produce white rice by pearling or whitening, and polishing (Hoseney 1994).

Milling barley Barley is shelled and the husk removed (via aspiration) before sifting and cutting. Barley may then be pearled, with extensive pearling (removal of over 50% of the original grain) producing pearl barley and as a by-product, barley flour (Kent & Evers 1994).

Milling oats Two different systems have developed: the traditional or dry-shelling system and the modern green-shelling system. As can be seen from Table 4, they share several similar steps (Kent & Evers 1994).

Table 4 Methods used to mill oats

Modern method	Traditional method
Width grading	
Shelling (by impact)	Stabilisation (inactivation of enzymes)
Stabilisation	Kiln drying
Kiln drying	Length grading
Length grading	Shelling (on stones)
Cutting	
Grinding (for oatmeal, oat flour and bran)	
Steaming and flaking (for rolled oats)	

Milling corn Corn may be dry or wet milled. After tempering, dry milling uses a degerminator (two cone-shaped surfaces, one rotating inside the other) to remove the hull and break the germ free from corn kernels. The endosperm is then reduced to grits using roller milling, similar to that used for wheat (Hoseney 1994). From this a number of products are manufactured such as hominy and polenta, the Italian porridge. Wet milling separates corn into its four basic components – starch, germ, fibre and protein. After steeping for 30–40 h, the next step in the process involves a coarse grind to separate the germ from the rest of the kernel. The remaining slurry is finely ground and screened to separate the fibre from the starch and protein. The starch is then separated from the remaining slurry. The starch can then be converted to syrup, or it can be made into several other products including paper, paints, ethanol and laundry detergents.

2.3.2 Technical consequences of milling

During milling, several technological changes occur. Firstly, there may be mechanical changes to the starch, which can increase the level of enzyme activity. These changes are important in bread making to provide access for the alpha-amylase to work and so are not intrinsically negative. The extent of this change will depend on the quality of the grain and the parameters of milling. Generally, the harder the grain, the greater the extent of changes.

Secondly, there may be changes to the proteins within the grains. During grinding, temperatures may reach 50–60°C, which can denature the cereal's proteins. This can lead to a lower wet gluten yield, which decreases the water absorption capacity of the flour. To prevent this, excessive heating of the milled material is avoided.

After milling, flour is stored or aged. If this occurs under normal atmospheric conditions, normal temperature and normal humidity, it can beneficially affect the quality of the flour. During ageing the flour will change in colour from cream to white and it will develop better baking properties (the gluten quality improves and its extensibility decreases). Although ageing of wheat flour may last up to 6 weeks, the major changes take place within the first 10–12 days after milling. Rye flour ages faster and so is aged for a shorter time (only about 2 weeks). Upon storage, rice undergoes 'after-ripening', a series of biochemical changes which can influence properties such as cooking time and stickiness (Kent & Evers 1994).

During milling there are risks of contamination from metallic fragments, mineral dust (*e.g.* sand), pests, microorganisms and heavy metals. However, controls set nationally and internationally limit the extent to which these contaminants can enter the food chain.

2.3.3 Nutritional consequences of milling

Fractionation of the grain during milling rather than the milling process *per se*, is important from a nutrition perspective. As fibre, vitamins and minerals tend to be concentrated in the outer bran and aleurone layers of the grain, the final nutrient content will depend on the extent to which these layers are removed during processing (MacEvilly 2003). Generally, the more processed the grain, the lower the proportion of vitamins in the final flour (Ottaway 1999). For example, white flour may have less than one-third of the mineral and vitamin content of wholegrains, although vitamins and minerals are often added back after milling (see section 4.1). Milling may decrease some of the bioactive substances (phytochemicals) that are found in cereals. For example, Liukkonen *et al.* (2003) found the content of several phytochemicals (*e.g.* lignans and phenolic acids) decreased after milling. For more information on phytochemicals, see section 3.2.4.

Starch and protein are less affected by processing as these nutrients are concentrated in the endosperm of the grain (Goldberg 2003). Milling, decortication, fermentation and germination will increase protein digestibility (due to the removal of fibre and enzymic breakdown of proteins) but milling and decortication reduce the level of lysine, the limiting amino acid in cereals (Macrae *et al.* 1993). Refined grains also have a higher glycaemic index (GI) than wholegrain products (Ludwig & Eckel 2002; see section 3.4 for more on GI). Some of the grain's lipids, which are mainly present in the germ and bran, are distributed during milling into other fractions (Southgate 1993).

2.3.4 Other processes

As well as milling, a range of other processes are used in the production of cereals and cereal products. Generally, the techniques used result in fragmentation of the food matrix and gelatinisation of the starch granules. This makes them readily digestible and generally they have higher GI values. Cereal protein may be damaged during some of the processes used to produce cereal products – *e.g.* baking can lead to lysine loss (Southgate & Johnson 1993). Antioxidant activity (which is relatively high in wholegrain cereal products) can be increased by browning reactions such as baking and toasting processes and may be due to the formation of intermediate substances from Maillard reactions with antioxidant activity (Slavin 2003).

Many cereal-based foods undergo processing involving heat. This may affect the bioavailability of minerals such as iron, calcium and zinc, *e.g.* availability may be improved because of the hydrolysis of phytates by phytase enzymes. Processes involving boiling may lead to losses of around 40% for most B vitamins, although losses of folate will be slightly higher. Losses during baking are generally lower, except for folate (MacEvilly 2003).

Recently, work in Sweden found baking starchy foods such as rice and cereals could lead to the formation of a substance called acrylamide. Acrylamide, which has been described as a 'probable carcinogen', has been found in a range of foods, including crisps, potato chips and cereal products. No link between acrylamide levels in food and cancer risk has been established and based on the evidence to date, the UK Food Standards Agency has advised the public not to change their diet or cooking methods (Kelly 2003). However, the EU's Scientific Committee on Food has endorsed recommendations made by Food and Agriculture Organisation (FAO)/ World Health Organization (WHO) in 2002 which include researching the possibility of reducing levels of acrylamide in food by changes in formulation and processing (see http://europa.eu.int/comm/food/fs/sc/scf/out131_en.pdf for more details).

Parboiling Rice is soaked in warm water (65°C) for 4–5 h before being steamed under pressure, dried and milled. This process increases the total and head yield of the rice and decreases the loss of nutrients during processing (see below). Polishing rice removes the bran layers and the germ, leading to substantial losses in B vitamins and a decrease in energy content [although the energy available is higher in milled rice because it contains less non-starch polysaccharides (NSP) on a weight for weight basis]. Before polishing, unhusked rice may be parboiled (steamed or boiled after soaking) to soften the husk. During this process, some of the water-soluble B vitamins located in the bran move into the endosperm, along with some of the oil. Although cooking and parboiling rice reduces its protein digestibility by 10–15%, there is a corresponding increase in the biological value, leading to an unchanged net protein utilisation value (Table 5).

Alkali processing The traditional method used to produce corn tortillas mixes maize with water and lime (cal-

Table 5 Comparison of selected nutrients in brown rice and white rice (per 100 g)

Nutrient	Brown rice, raw	White rice (easy cook), raw
Energy (kcal/kJ)	357/1518	383/1630
Fat (g)	2.8	3.6
Protein (g)	6.7	7.3
Fibre (as NSP) (g)	1.9	0.4
Thiamin (mg)	0.59	0.41
Riboflavin (mg)	0.07	0.02
Niacin equivalents (mg)	6.8	5.8
Folate (μg)	49	20

NSP, non-starch polysaccharides.

Source: Food Standards Agency and Institute of Food Research 2002.

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cium hydroxide). After cooking, the mixture is steeped overnight before being washed with fresh water to remove the loosened pericarp and any residual alkali (Macrae *et al.* 1993).

Fermentation Fermentation is used to produce a number of cereal products including bread, and alcoholic beverages such as beer, vodka and whiskey. Examples of fermented cereal foods include kenkey, made from a fermented maize dough in Ghana and tapé ketan, a rice dessert in Indonesia (Macrae *et al.* 1993). During bread making, fermentation produces carbon dioxide making the dough rise and increasing its volume. During the proving stage, mechanically damaged starch grains are broken down by amylase to produce maltose, which is important for maintaining yeast activity (and therefore gas production). In addition to yeast, lactic acid bacteria are used in the production of sourdough bread to provide an acidic flavour to the final product. Some of the bioactive substances in rye increase in sourdough baking (Liukkonen *et al.* 2003). The bacteria also affect the dough proteins, making the dough stronger. In alcohol production, fermentation produces ethanol and carbon dioxide. In other fermented cereal products, the bioavailability of minerals may be higher than in similar non-fermented products due to the partial breakdown of the phytate. Fermentation may also improve protein quality because of bacterially produced lysine and by improving protein digestibility (Macrae *et al.* 1993).

Extrusion The extrusion process uses a screw press with a restricted opening to produce a shaped food product. Extrusion cooking uses this process in addition to heat (a high-temperature short-time procedure) to manufacture a range of food products, including breakfast cereals and pasta. Gualberto *et al.* (1997) found extrusion had no effect on the insoluble fibre content of wheat bran but observed decreased amounts in rice and oat brans. The amount of soluble fibre increased in all three brans after extrusion, except at the maximum screw speed (100% maximum rotations per minute). The phytate content of the three cereal brans was not affected by extrusion. Sandberg *et al.* (1986) found that extrusion cooking could impair the digestion of phytate in a high-fibre cereal product owing to loss of phytase activity. No effect was seen in absorption of iron and calcium but a small decrease in the absorption of zinc, magnesium and phosphorus led the authors to suggest that this could have implications for foodstuffs consumed frequently (Kivisto *et al.* 1986). In a more recent study, Fairweather-Tait *et al.* (1989) found extrusion cooking had no effect on the retention of iron or zinc in adults.

Other processes In the production of breakfast cereals, a number of other processes may be used (Fast & Caldwell 2000). For example, flaked cereals can be made from wholegrains or parts of the wholegrain or from finer flour materials, with great pressures being used to flatten the prepared material into flakes. Puffed cereals are produced using either puffing guns (which are capable of holding very high temperature and high-pressure steam) or an oven. Shredded cereals are produced by passing the tempered grain between two rollers, one of which is grooved and the other smooth. The grain is squeezed into the grooves of the roller and emerges as strands which are removed, accumulated in layers and formed into biscuits or bite-sized pieces.

2.4 Cereals and food safety

Damage to cereals can occur in the field as well as after harvesting. In addition to problems with pests, moulds and fungi can contaminate cereals.

2.4.1 Pests

Infestation of cereal crops by pests can be a problem, both before and after harvest. Insects (*e.g.* mites and weevils) cause the most damage in stored cereals. Insects can produce substances with unpleasant tastes and smells (such as uric acid) and some transmit pathogenic bacteria. They can also affect the cereal's nutritional value, for example, decrease the carbohydrate content and increase free fatty acid levels (Chelowski 1991). Jood & Kapoor (1994) found insects could affect the vitamin content of cereals, decreasing the thiamin content by up to 69%, riboflavin content by up to 67% and

Table 6 Examples of moulds producing mycotoxins in cereals

Mould	Mycotoxin produced
Aspergillus flavus	Aflatoxins B1 and B2
Penicillium verrucosum (temperate regions)	Ochratoxin
Aspergillus ochraceus (tropical regions)	
Fusarium species	Fumonisins
	Zearlenone
	Deoxynivalenol

niacin by up to 32%. When infestations are detected in a silo or a ship, insecticides may be used, although the type of insecticide and the level used are tightly controlled (Macrae *et al*. 1993). Birds and rodents can also contaminate stored cereals and cause food safety problems (Appert 1987).

2.4.2 *Other contaminants*

There is potential for contamination of cereals and cereal products at many different stages, *e.g.* during growth, harvest and storage. Mycotoxins are toxic chemical substances produced by certain forms of mould under specific conditions. A number of moulds produce toxins (see Table 6). The most important mycotoxin with respect to cereals is produced by *Aspergillus flavus* (Macrae *et al*. 1993). As mycotoxins are natural contaminants of cereals, it is normal for small quantities to appear in harvested cereals. Mycotoxins are only a threat to human health if they are absorbed in large quantities. A range of preventative strategies are used to prevent the formation of mycotoxins before and after harvest. Although mycotoxins are relatively stable, certain manufacturing processes can reduce their level, *e.g.* milling of white flour removes deoxynivalenol which is concentrated in the external layers of the bran (Quillien 2002).

Ergot is a fungus that can be found on a large number of plants around the world (Lorenz 1979). *Claviceps purpurea*, the ergot of medical importance, grows on rye. Consumption of infected rye is harmful and can lead to ergotism (also called Saint Anthony's fire), which produces gangrenous necrosis and hallucinations (Macrae *et al*. 1993; Bender & Bender 1999). Ergot rarely enters commercial food channels because of strict grain standards but ergotism still occurs in animals from time to time (Lorenz 1979).

Other problems that occur in cereals include rusts (a fungal disease caused by species of Puccinia) and smut diseases, which are caused by fungi which produce masses of soot-like spores on the leaves, grains or ears.

2.5 Key points

- Wheat is the largest cultivated cereal crop, accounting for 30% of the world's cereal production. Rice is the second most important crop on a world basis, accounting for 21% of the world's cereal production.
- Post-harvest, good grain storage is important to minimise losses, with moisture content a key factor.
- Cereals undergo a range of processing, the most common being milling, which affect their technological and nutritional properties. Generally, the final nutrient content of a cereal will depend on the extent to which the outer bran and aleurone layers are removed during processing, as this is where the fibre, vitamins and minerals tend to be concentrated. Recently, acrylamide has been found in starchy baked foods. No link between acrylamide levels in food and cancer risk has been established and based on the evidence to date, the UK Food Standards Agency has advised the public not to change their diet or cooking methods (Kelly 2003). However, the EU's Scientific Committee on Food has endorsed recommendations made by FAO/WHO which include researching the possibility of reducing levels of acrylamide in food by changes in formulation and processing.
- There is potential for contamination of cereals and cereal products by pests, mycotoxins, rusts and smuts.

3 The role of cereals in health and disease

Cereals have a long history of use by humans, dating back to prehistoric times. Cereals are staple foods, with current estimates of annual cereal consumption at 166 kg per capita in developing countries and 133 kg in developed countries (FAO 2003). Cereals provide a range of macro- and micronutrients and a high consumption of cereals has been associated with a decreased risk of developing several chronic diseases.

3.1 History of cereals in the diet

There is evidence to suggest that wild cereals were eaten by human hunter-gatherers in ancient times (Toussaint-Samat 1994). For example, sorghum has been used since prehistoric times in Africa, Asia and Europe and probably originated in North Africa around 3000 BC (Kent & Evers 1994). The origin of rice may be traced to a plant grown in India at the same time, but it is first mentioned historically in China in 2800 BC. This is roughly the same time maize was being grown in America. While wild barley and wheat were grown in parts of the Middle East around 10 000 BC, these varieties produced low yields because they were brittle and shed their seeds.

Due to natural mutations, more sturdy varieties developed and these were selected for cultivation and cereal crops spread, reaching Britain sometime between 4000 and 2000 BC (Vaughan & Geissler 1997). Rye was domesticated in Germany at about the same time (Kent & Evers 1994).

Cereals were obviously an important part of our ancestors' lives, as cereals appear in a number of myths and legends. For example, barley and wheat were viewed as gifts from one of the gods, while the Aztecs believed the same for corn (Toussaint-Samat 1994; Werner 1997). Cereals play a pivotal role in a number of different religions, including rice in the Japanese religion of Shinto and bread in Christianity.

3.2 Nutritional value of cereals

Cereals are staple foods, providing a major source of carbohydrate, protein, B vitamins and minerals for the world's population. As well as containing a range of phytochemicals which may provide some of the health benefits seen among populations consuming diets based on plant foods (see Goldberg 2003), cereals also contain a number of anti-nutrients.

3.2.1 Macronutrients

Carbohydrate Cereals are often classed as carbohydrate-rich foods, as they are composed of approximately 75% carbohydrate. Starches, the major component of the cereal, occur in starch granules in the endosperm. Starch granules differ in size (*e.g.* in rice they have a diameter of only 5 μm, while in wheat they may be 25–40 μm) and shape (either large, lens-shaped granules or small, spherical granules). The ratio of amylose to amylopectin within the starch granules varies, depending on the cereal and its variety. Within common varieties of cereals, 25–27% of starch is present as amylose, while in waxy varieties (*e.g.* rice and corn) most of the starch is amylopectin (see Fig. 5). However, in cereal products, a proportion of this starch is not digested and absorbed in the small intestine. This is referred to as *resistant starch* and it appears to act in a similar way to dietary fibre. Four categories of resistance have been defined (Baghurst *et al.* 1996):

- RS1 refers to starch that is physically inaccessible for digestion as it is 'trapped' (*e.g.* intact wholegrains and partially milled grains).
- RS2 refers to native resistance starch granules (*e.g.* found in high amylose maize starch).
- RS3 refers to retrograded starch (*e.g.* found in cooked and cooled potatoes, bread and some types of cornflakes).
- RS4 refers to chemically modified starch (*e.g.* commercially manufactured starches).

A small amount of free sugars is also present (~1–2%), mainly as sucrose but low concentrations of maltose and very low concentrations of fructose and glucose occur.

Protein Cereals contain about 6–15% protein (Goldberg 2003). The major storage proteins in wheat are gliadins and glutenins, while in rice it is glutelin (oryzenin), in maize it is prolamin (zein); barley has hordeins and glutelins, and in oats there are albumins and globulins (Kulp & Ponte 2000). Although cereals provide a good range of amino acids, the building blocks of proteins, some are present in relatively low amounts. Essential amino acids must be supplied by the diet, and from these

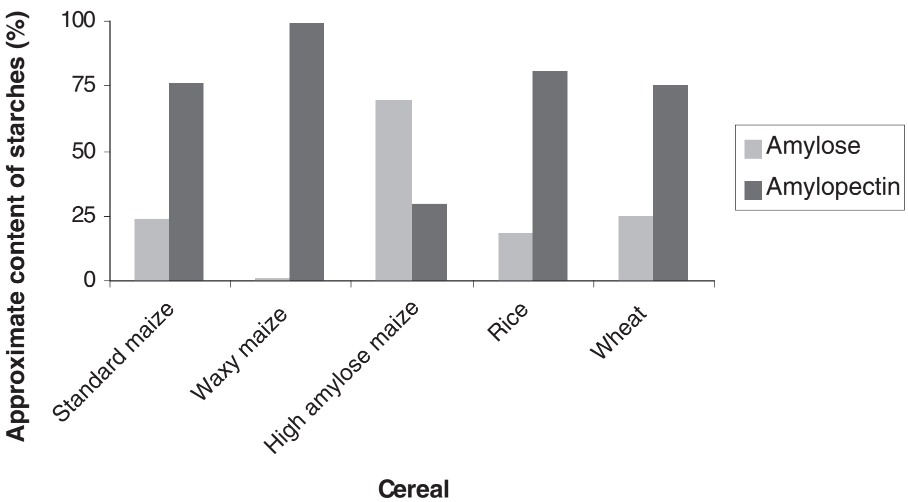

Figure 5 Approximate amylose and amylopectin content of selected cereals.

Table 7 Essential amino acid composition of cereal grains

Amino acid (g/ 100 g protein)	Wheat (hard)	Rice		Maize		Barley	Oats	Rye	Millet (average of 7 types)	Sorghum	
		B	M	N	HL					N	HL
Phenylalanine	4.6	5.2	5.2	4.8	4.3	5.2	5.4	5.0	5.5	5.1	4.9
Histidine	2.0	2.5	2.5	2.9	3.8	2.1	2.4	2.4	2.0	2.1	2.3
Isoleucine	3.0	4.1	4.5	3.6	3.4	3.6	4.2	3.7	3.8	4.1	3.9
Leucine	6.3	8.6	8.1	12.4	9.0	6.6	7.5	6.4	10.9	14.2	12.3
Lysine	2.3	4.1	3.9	2.7	4.3	3.5	4.2	3.5	2.7	2.1	3.0
Methionine	1.2	2.4	1.7	1.9	2.1	2.2	2.3	1.6	2.5	1.0	1.6
Threonine	2.4	4.0	3.7	3.9	3.9	3.2	3.3	3.1	3.7	3.3	3.3
Tryptophan	2.4	1.4	1.3	0.5	0.9	1.5	-	0.8	1.3	1.0	0.9
Valine	3.6	5.8	6.7	4.9	5.6	5.0	5.8	4.9	5.5	5.4	5.1

B, brown; M, milled; N, normal; HL, high-lysine.
Source: Macrae *et al.* 1993.
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Table 8 Fatty acid profiles of selected cereals

Fat & fatty acids (g/100 g food)	Barley, pearl, raw	Oatmeal, quick cook, raw	Wheat flour, white	Rye flour	Rice, brown, raw	Rice, white, raw
Total fat	1.7	9.2	1.2	2.0	2.8	3.6
Saturated fatty acids	0.29	1.61	0.16	0.27	0.74	0.85
Cis-monounsaturated fatty acids	0.14	3.34	0.13	0.21	0.66	0.91
Polyunsaturated fatty acids:						
Total cis	0.77	3.71	0.51	0.95	0.98	1.29
n-6 (as 18:2)	0.70	3.52	0.48	0.82	0.94	1.26
n-3	0.07	0.19	0.03	0.13	0.04	0.03

Source: Ministry of Agriculture, Fisheries and Food 1998.
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the human body is able to make other (termed non-essential) amino acids for itself (Table 7). The essential amino acid that is in shortest supply in relation to need is termed the limiting amino acid. For cereals the limiting amino acid is lysine, except for rye, where tryptophan is the first limiting amino acid (Macrae *et al.* 1993). More favourable essential amino acid compositions can be found in rice, rye, barley and high-lysine cultivars (*e.g.* maize, sorghum and barley) (Macrae *et al.* 1993). Combining cereals with other plant foods (*e.g.* rice and beans) can compensate for these limiting amino acids.

Lipids Although the germ is the richest source of lipids, overall, lipids are only a minor component of cereals, with the amount varying from a lipid content of 1–3% in barley, rice, rye and wheat, to 5–9% in corn and 5–10% in oats, on a dry-matter basis (Southgate 1993). This lipid fraction is rich in the essential fatty acid linoleic acid (C18:2) (Table 8).

3.2.2 Micronutrients

Cereals can contribute to vitamin and mineral intake, although the micronutrient content will depend on the proportion of germ, bran and endosperm present (see section 2.3). The pericarp, germ and aleurone layer are rich in vitamins and minerals so refined cereal products lose some of these nutrients, although in the UK legislation requires the addition of thiamin, niacin, calcium and iron to wheat flour (except wholemeal). Such legislation currently varies between countries in the EU.

Vitamins Cereals contain no vitamin C or vitamin B_{12}, no vitamin A and, apart from yellow corn, no beta-carotene (Courdain 1999). However, cereals are an important source of most B vitamins, especially thiamin, riboflavin and niacin (Kulp & Ponte 2000). Cereals also contain appreciable amounts of vitamin E (Table 9).

Table 9 Vitamin content of selected cereals (mg/per 100 g, unless specified)

Vitamin	Vitamin E	Thiamin	Riboflavin	Niacin equivalent (μg)	Vitamin B_6 (μg)	Folate (μg)
Wheat flour, white, plain	0.30	0.31†	0.03	3.6†	0.15	22
Wheat flour, wholemeal	1.40	0.47	0.09	8.20	0.50	57
Rice, easy cook white, raw	(0.10)	0.41	0.02	5.8	0.31	20
Rice, brown, raw	0.80	0.59	0.07	6.80	N	49
Popcorn, plain	11.03	0.18	0.11	1.7	0.20	3
Oatmeal, quick cook raw	1.50	0.90	0.09	3.4	0.33	60
Barley, pearl raw*	0.40	0.12	0.05	4.8	0.22	20
Rye flour, whole	1.60	0.40	0.22	2.6	0.35	78
Millet flour*	Trace	0.68	0.19	2.8	N	N

*From Holland *et al.* 1988. †These values are for fortified flour.
N, the nutrient is present in significant quantities but there is no reliable information on the amount; (), estimated value.
Source: Food Standards Agency and Institute of Food Research 2002.
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Table 10 Mineral content of selected cereals (mg/per 100 g, unless specified)

Mineral	Na (mg)	K (mg)	Ca (mg)	Mg (mg)	Fe (mg)	Zn (mg)	Se (μg)
Wheat flour, white, plain	3	150	140†	20	2.0†	0.6	2
Wheat flour, wholemeal	3	340	38	120	3.9	2.9	6
Rice, easy cook white, raw	4	150	51	32	0.5	1.8	13
Rice, brown, raw	3	250	10	110	1.4	1.8	10
Popcorn, plain	4	220	10	81	1.1	1.7	N
Oatmeal, quick cook raw	9	350	52	110	3.8	3.3	3
Barley, pearl raw*	3	270	20	65	3.0	2.1	(1)
Rye flour, whole	(1)	410	32	92	2.7	3.0	N
Millet flour*	21	370	40	N	N	N	N

*From Holland *et al.* 1988. †These values are for fortified flour.
N, the nutrient is present in significant quantities but there is no reliable information on the amount; ( ), estimated value.
Source: Food Standards Agency and Institute of Food Research 2002.
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Minerals Cereals are low in sodium and are a good source of potassium, in common with most plant foods. Wholegrain cereals also contain considerable amounts of iron, magnesium and zinc, as well as lower levels of many trace elements, *e.g.* selenium. Rice contains the highest level of selenium among the cereal grains, providing between 10 and 13 μg per 100 g (Table 10). The selenium content of a cereal will vary depending on the selenium content of the soil; for example, the selenium content of wheat-grain can range from 0.001 μg per 100 g to 30 μg per 100 g (Lyons *et al.* 2003). Wheat grown in North America generally has a higher selenium content compared to that grown in Europe and the switch to European wheat in recent years is suggested as the main explanation of falling selenium intake in the UK, although the effect (if any) of this decrease on health is not currently known (Goldberg 2003).

3.2.3 Non-starch polysaccharides

All cereals are a rich source of NSP. There are two types of NSP – insoluble and soluble – and, although both may help with weight control (by delaying food leaving the stomach), they have different effects in the body (see section 3.3). The insoluble NSP content of most cereals is similar, while the composition of the water-soluble NSP varies. Arabinoxylans are the main water-soluble NSP in wheat, rye and barley, while in oats it is the beta-glucans. The amounts of beta-glucans and arabinoxylans are higher in barley, oats and rye compared to wheat (on a dry weight basis, 3–11%, 3–7%, 1–2% and <1%, respectively) (Wood 1997).

3.2.4 Phytochemicals

Cereals contain a range of substances, which may have health-promoting effects, that are often referred to as phytochemicals or plant bioactive substances (see Goldberg 2003). Although flavonoids are only present in cereals in small quantities, a number of other antioxidants are present, including small amounts of tocotrienols, tocopherols and carotenoids. In laboratory studies, wholegrain breakfast cereals have been found to have an antioxidant content similar to fruits and vegetables (Miller *et al*. 2000) and one study suggests that the major contributors of overall antioxidant activity are bound phytochemicals (Adom & Li 2002). Lignans are a type of phytoestrogen found in cereals, and although the amount may be low (*e.g.* compared to that in linseed), cereals may be an important source because of the large quantities eaten daily.

3.2.5 Anti-nutrients

As previously mentioned, cereals contain relatively high levels of phytate. On a dry weight basis, corn contains 0.89% phytate, soft wheat 1.13%, brown rice 0.89%, barley 0.99% and oats 0.77% (Cheryan 1980). In most cereals, the phytate is concentrated in the aleurone layer and, to a lesser extent, the germ (Làsztity & Làsztity 1990). This means that milling affects the level of phytate of most cereals, *e.g.* white flour has almost no phytate remaining (Anon 1979). Phytate can bind minerals such as iron, calcium and zinc, and there is some evidence showing decreased absorption of these minerals in the presence of phytate (*e.g.* McCance and Widdowson observed a decreased absorption of calcium in humans when phytate was added to white bread) (Harris 1955). The extent to which this affects nutrient status will depend on a number of factors, including the amount of phytate hydrolysed during processing or the amount that is digested in the gut; the concentration of phytate and minerals in the food and the overall diet and the nutrient status of the individual. This effect may be of particular relevance to those people consuming a low-calorie diet (Làsztity & Làsztity 1990).

Tannins, which are found for example in brown sorghum, can bind and precipitate protein, decreasing its digestibility. Germination and treatment of sorghum with calcium oxide, potassium carbonate, ammonium bicarbonate or sodium bicarbonate improves the nutritional value of the grain. Pearl millet barley contains a *goitrogen* (thioamide), found in the bran and endosperm. Trypsin inhibitors, which can impair protein digestability, have also been isolated in pearl millet and rye, although these are normally deactivated by heating (Bender & Bender 1999). Rye also contains other anti-nutrients, which have an impact in animal nutrition but are of little concern to humans as they are either removed during processing or destroyed during baking.

3.3 Contribution of cereals and cereal products in the diet

Cereal products play a central role in most countries and are staple foods for much of the world's population. In the UK's *Balance of Good Health* food model, cereals and cereal products are grouped with bread and potatoes and this group of foods should form a main part of meals (Fig. 6). The dietary guidelines accompanying the *Balance of Good Health* encourage 'plenty of foods rich in starch and fibre'. Many of the foods in this group could be described as wholegrain foods, although no legal definition currently exists in the UK (although the American definition of a minimum of 51% wholegrain ingredient has been used by the Joint Health Claims Initiative). Currently America is the only nation to make specific recommendations regarding wholegrain foods (three servings a day) (Lang & Jebb 2003).

Table 11 shows the contribution that cereals and cereal products (including bread, pasta, breakfast cereals, biscuits, cakes and pastries) make to the UK diet. Cereals and cereal products are an important source of

Table 11 Average contribution of cereals and cereal products to the nutrient intake in the UK

	% contribution of cereals to average intake of nutrients		
Nutrient	Boys*	Girls*	Adults†
Energy	35	33	31
Protein	27	26	23
Carbohydrate	45	42	45
Fat	22	21	19
Fibre (as NSP)	40	37	42
Thiamin	43	38	34
Riboflavin	34	31	24
Niacin	38	34	27
Folate	44	37	33
Vitamin B_6	30	26	21
Vitamin D	37	35	21
Iron	55	51	44
Calcium	27	27	30
Sodium	40	38	35
Potassium	15	14	12

NSP, non-starch polysaccharides.
*Children National Diet and Nutrition Survey (NDNS) from Gregory *et al.* 2000. †Adult NDNS data from Henderson *et al*. 2003a, 2003b.
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Figure 6 *Balance of Good Health* (British Nutrition Foundation version).

magnesium (providing 27% of the average adult intake) and zinc (providing 25% of the average adult intake) (Henderson *et al.* 2003b). It is also estimated that about one-fifth of the UK's selenium intake is from cereals and cereal products (Goldberg 2003). Cereal products also contribute a considerable proportion of sodium, mainly from bread (15%, 14% and 14% for boys, girls and adults, respectively). Although cereals are naturally low in sodium, during production of cereal products sodium is added. If manufacturers continue to reduce the sodium content of cereal products it will help the population to reduce average total sodium intake.

As can be seen from Table 11, cereals and cereal products play an important role in the diet and are the main source of many nutrients for both children and adults. This is in part due to the mandatory fortification of all wheat flour (apart from wholemeal) with iron, calcium, thiamin and niacin, and the voluntary fortification of breakfast cereals. This is demonstrated by the 20% contribution fortified breakfast cereals make to the average intake of iron in the UK adult population.

3.3.1 Bread

Bread making goes back to prehistoric times, when a mixture of grass seeds was ground into a crude form of flour, to which water was added to form a dough (Patient & Ainsworth 1994). Bread is made from four ingredients – flour, water, yeast and salt and in the UK most bread is produced using wheat flour, although other flours, *e.g.* rye, are sometimes used. Different types of bread are produced from wheat flour depending on the proportion of the grain used, with brown breads being made from flour of an intermediate extraction rate (about 80–85%).

The traditional method of bread making involves the mixing of the four ingredients to form a dough, which is then kneaded to develop the gluten, before being left to stand (during which time fermentation occurs). As this method is quite time-consuming and labour-intensive, a mechanical method, the Chorleywood process, was developed which uses a mechanical mixer, a fast-acting dough improver and a small amount of fat (Kent & Evers 1994).

White bread may be the most commonly eaten food in the UK; data from the recent adult National Diet and Nutrition Survey (NDNS) indicated that 93% of men and 89% of women ate it during the 7-day recording period (Henderson *et al.* 2002). In the UK, weekly household consumption of bread has decreased by almost 1 kg since the 1940s. However, over the last 10 years there has been an increase in breads such as French bread, naan bread, pitta bread and bagels (DEFRA & National Statistics 2001). The current average adult intake of bread (including wholemeal, soft grain and other bread) is about 91 g a day, roughly three slices (Henderson *et al.* 2002).

The typical nutrient content of different breads is given in Table 12. In terms of macronutrients, about 40% of bread is carbohydrate and 8–9% is protein; the breads are all low in fat (less than 3 g of fat/100 g). However, the fibre content is significantly higher in wholemeal and brown bread than white bread.

3.3.2 Breakfast cereals

Developed in the late 19th century in America and introduced to the UK in the early 20th century, RTE breakfast cereals are an important source of nutrients. For example, in a sample of schoolchildren in Northern Ireland, fortified RTE breakfast cereals were associated with higher daily intakes of most micronutrients and fibre, and with a macronutrient profile consistent with current nutritional recommendations. Inadequate intakes of riboflavin, niacin, folate and vitamin B_{12} (and iron in girls) were more likely in those children not consuming fortified breakfast cereals (McNulty *et al.* 1996). Although vitamin D is not usually associated with breakfast cereals, because of fortification of RTE breakfast cereals, the recent NDNS report indicated that they now account for 13% of the average daily vitamin D intake in UK men and women (Henderson *et al.* 2003b) (Fig. 7). Similarly, in children, breakfast cereals account for 20% of the average daily vitamin D intake in girls and 24% in boys (Gregory *et al.* 2000).

Some recent work in schoolchildren has suggested that breakfast cereals may help maintain mental performance over the morning compared to no breakfast or a glucose drink (Wesnes *et al.* 2003). A small study in adults also found that a high-fibre carbohydrate-rich breakfast was associated with the highest post-breakfast alertness rating and the greatest alertness between breakfast and lunch (Holt *et al.* 1999). A larger study found an association between breakfast cereal consumption and subjective reports of health, with those adults who ate breakfast cereal every day reporting better mental and physical health, compared to those who consumed it less frequently (Smith 1999).

3.3.3 Pasta

Pasta is traditionally made from very hard (durum) wheat, which is high in protein, and water. The mixture is kneaded to produce a very stiff dough which is then extruded, cut and dried. Pasta was bought to Britain in the 18th century, and in 2000/2001 in Britain, among those men and women who ate pasta (52% men and 53% of women), the mean consumption was 406 g and

Table 12 Typical nutrient composition per 100 g of bread

Nutrient	White	Brown	Wholemeal
Energy (kcal/kJ)	219/931	207/882	217/922
Protein (g)	7.9	7.9	9.4
Carbohydrate (g)	46.1	42.1	42
Total sugars (g)	3.4	3.4	2.8
Starch (g)	42.7	38.7	39.3
Fat (g)	1.6	2.0	2.5
Fibre (as NSP) (g)	1.9	3.5	5.0
Thiamin (mg)	0.24	0.22	0.25
Niacin equivalents (mg)	3.6	4.9	6.1
Folate (μg)	25	45	40
Iron (mg)	1.6	2.2	2.4
Calcium (mg)	177	186	106

NSP, non-starch polysaccharides.

Source: Food Standards Agency and Institute of Food Research 2002.

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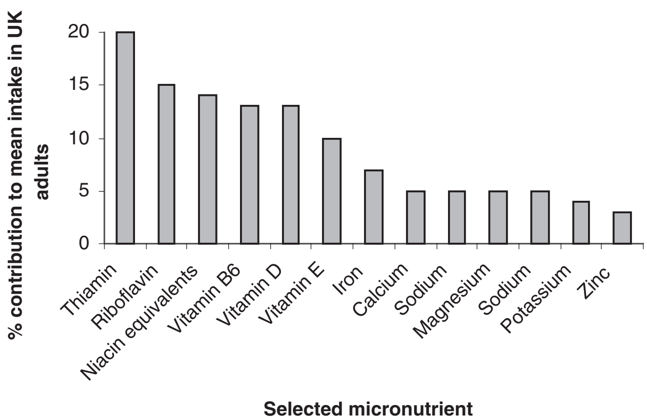

Figure 7 Contribution of breakfast cereals to the mean vitamin and mineral intake of UK adults (Henderson *et al.* 2003b).

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Table 13 Nutrient content of white and wholemeal pasta (per 100 g)

Nutrient	White (boiled)	Wholemeal (boiled)
Energy (kcal/kJ)	104/442	113/485
Protein (g)	3.6	4.7
Carbohydrate (g)	22.2	23.2
Total sugars (g)	0.5	1.3
Starch (g)	21.7	21.9
Fat (g)	0.7	0.9
Fibre (as NSP) (g)	1.2	3.5
Thiamin (mg)	0.01	0.02
Niacin equivalents (mg)	1.2	2.3
Iron (mg)	0.5	1.4
Calcium (mg)	7	11

Source: Food Standards Agency and Institute of Food Research 2002.
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330 g a week, respectively (Henderson *et al*. 2002). The nutrient content of white and wholemeal pasta is shown in Table 13.

3.3.4 Biscuits, buns, cakes and pastries

Although cereal foods are generally low in fat, this subgroup contributes 7% to the average daily intake of total fat in adults and 5% in children (Gregory *et al*. 2000; Henderson *et al*. 2003a). Within the *Balance of Good Health*, therefore, they do not fall into the same category as the cereal products discussed above. Biscuits and buns, cakes and pastries form part of the group of foods containing fat; foods containing sugar.

3.3.5 Other foods containing cereals

Cereals and cereal products are used in a wide range of other foods. Cereal-based porridges are traditionally used as weaning foods in many parts of the world and within the UK baby cereals are often used at the first stage of weaning.

3.4 Cereals in health and disease

There is much interest in understanding the role of particular foods, such as cereals, in the diet and their effect on health. Some of the work on cereals has focused specifically on wholegrain cereals and work suggests that people who eat wholegrains may have better nutrient intake profiles. For example, people in the USA who ate wholegrains had higher intakes of vitamins and minerals, and lower intakes of total fat, saturates and added sugars compared to those who did not eat wholegrains (Cleaveland *et al*. 2000). Cereals may also have a range of health benefits as discussed below.

3.4.1 Energy balance

Cereal foods have a relatively low energy density, and foods rich in wholegrain cereals may help reduce hunger as they are relatively bulky (Holt *et al*. 1999; Saltzman *et al*. 2001). Cereals may also affect body weight regulation through effects on hormonal factors (Koh-Banerjee & Rimm 2003). By focusing on increasing cereal intake, it is possible to achieve a reduction in consumption of other foods and a reduction in fat intake. For example, a small study using free-living subjects found that including 60 g of breakfast cereal with semi-skimmed milk every day decreased the average intake of energy from fat by 5.4%, with a similar increase in energy contribution from carbohydrate (Kirk *et al*. 1997). In another small study, 14 subjects consumed four different breakfasts of the same energy content but with differing macronutrient content – two fat-rich and two carbohydrate-rich (low or high fibre). The high-fibre, carbohydrate-rich breakfast was the most filling meal and was associated with less food intake during the morning and at lunch. Hunger returned at a slower rate after this meal than after the low-fibre, carbohydrate-rich meal. Both fat-rich breakfasts were more palatable but less satiating than the carbohydrate-rich meals (Holt *et al*. 1999). The recent WHO/FAO expert committee report on nutrition and chronic diseases suggested that a high intake of NSP may be a protective factor against overweight and obesity (WHO/FAO 2003).

3.4.2 Glycaemic index (GI)

The GI is used for classifying carbohydrate-containing foods. It can be defined as 'the incremental area under the blood glucose curve after consumption of 50 g carbohydrate from a test food, divided by the area under the curve after eating a similar amount of control food (generally white bread or glucose)' (Ludwig & Eckel 2002). The glycaemic load (GL) assesses the total glycaemic effect of the diet and is the product of dietary GI and total amount of dietary carbohydrate (Jenkins *et al*. 2002). The rate of digestion and absorption of carbohydrates is influenced by a range of factors (Pi-Sunyer 2002), including:

- the nature of the monosaccharide components;
- the nature of the starch (*e.g.* the amylose to amylopectin ratio);

- cooking or food processing; (*e.g.* milling increases the GI of cereals);
- other food components (*e.g.* fat, protein and fibre).

Several metabolic effects may be related to the reduced rate of glucose absorption after a low-GI food, *e.g.* a lower blood glucose concentration and a reduced post-prandial rise in gut hormones and insulin, maintaining suppression of free fatty acids. The GI concept suggests a possible role for the rate of carbohydrate digestion in the prevention and treatment of chronic disease. There may also be a role for low-GI foods in weight management, as they promote satiety. Although one study observed that a similar amount of weight loss occurred with a high-GI diet as with a low-GI diet (Wolever *et al.* 1992), several intervention studies have found that energy-restricted diets based on low-GI foods produce greater weight loss than those based on high-GI foods (Brand-Miller *et al.* 2002). A systematic review highlighted inconsistent results in short-term studies measuring appetite sensations following low GI *vs.* high-GI foods. In terms of weight loss, the 20 longer-term intervention studies found no advantage in using a low-GI diet compared to a high-GI diet (1.5 kg loss on a low-GI diet *vs.* 1.6 kg on a high-GI diet) (Raben 2002). Several epidemiological studies have also discovered a relationship between a high-GI diet and chronic disease, *e.g.* coronary heart disease (CHD – see section on heart health), type 2 diabetes (see section on diabetes) and cancer (Jenkins *et al.* 2002).

A high-fibre wheat or high-fibre rye diet has been shown to decrease post-prandial plasma insulin by 46–49% and post-prandial plasma glucose by 16–19% in overweight, middle-aged men compared to a low-fibre diet but it is unclear if subjects were healthy, or had impaired glucose tolerance or type 2 diabetes (McIntosh *et al.* 2003). Although the authors suggested more comprehensive testing should be undertaken, they concluded that it was promising that even in the short term, wholegrain foods were capable of decreasing the glycaemic response.

The recent WHO/FAO report on nutrition and chronic disease associated low-GI foods with an overall improvement in glycaemic control in people with diabetes, and several countries educate people with diabetes about GI. The WHO/FAO report also listed low-GI foods as a possible factor in decreasing the risk of developing type 2 diabetes and reducing the risk of weight gain (WHO/FAO 2003).

3.4.3 Heart health

Several large cohort studies in America, Finland and Norway have found that people eating relatively large amounts of wholegrain cereals have significantly lower rates of CHD and stroke. A recent review by Hu (2003) identified several prospective cohort studies showing an inverse association between wholegrain consumption and risk of cardiovascular disease (CVD) (Table 14). In addition, the prospective Physicians' Health Study in the USA following ~86 000 men for over 5 years found men in the highest category for wholegrain breakfast cereal intake (≥ 1 serving/day) had a 20% decreased risk of dying from CVD, compared to those in the lowest category [relative risk (RR) of 0.80] (Liu *et al.* 2003). No significant associations between total or refined breakfast cereal intakes and CVD mortality were found.

One way wholegrain cereals may be having an effect on heart health is the effect of soluble fibre on cholesterol levels. A meta-analysis of 67 controlled studies found soluble fibre (2–10 g/day) was associated with small but significant reductions in total cholesterol and low density lipoprotein cholesterol (LDL-C) concentrations. No significant difference was seen between soluble fibre from oat, psyllium or pectin. There was, however, substantial heterogeneity between studies, suggesting the effects of fibre are not uniform. Although in practical terms, such an effect would be modest (*e.g.* 3 g of soluble oat fibre could decrease total and LDL-C concentrations by ~0.13 mmol/L), there is a US-approved health claim for soluble fibre and the risk of CHD (see

Table 14 Wholegrain cereal consumption and decreased risk: prospective cohort studies reviewed by Hu (2003)

Condition	Subjects	Decreased risk (adjusted RR)	Reference
Stroke	75 521 women	36% (0.64)	Liu *et al.* 2000
CHD	75 521 women	25% (0.75)	Liu *et al.* 1999
Fatal CHD	34 492 women	30% (0.70)	Jacobs *et al.* 1998
Non-fatal heart attack	31 208 men & women	44% (0.56)	Fraser *et al.* 1992
CHD	31 208 men & women	11% (0.89)	Fraser *et al.* 1992

RR, relative risk; CHD, coronary heart disease.

section 3.5 for more on health claims) (Brown *et al.* 1999). As well as encouraging consumption of foods rich in soluble fibre, there may be scope for increasing the soluble fibre content of cereal products. In the only randomised controlled trial (RCT) using men with a history of myocardial infarction (the Diet and Reinfarction Trial study), advice to increase cereal fibre had no effect on CHD or all-cause mortality (Ness *et al.* 2002), but further work in healthy individuals is warranted.

Another area of interest is the influence of GI on blood lipids. Two observational studies have shown a negative relationship between GI and high density lipoprotein cholesterol (HDL-C) concentrations, suggesting a low-GI diet may preserve HDL-C levels (Jenkins *et al.* 2002). Several RCTs have shown that, in people with diabetes, diets containing a large proportion of the dietary carbohydrate as low-GI foods have shown improved blood lipids, independent of dietary fibre intake (Mann 2001).

There may currently be insufficient evidence to demonstrate a cause and effect between heart health and wholegrain foods, but the WHO/FAO stated that there was a 'probable' level of evidence demonstrating NSP and wholegrain cereals decrease the risk of CVD (WHO/FAO 2003). Several health claims in the area of heart health and wholegrain cereals have been approved (see section 3.5).

3.4.4 Diabetes

Prevention of diabetes A potential role for fibre in the prevention of diabetes was put forward over 30 years ago, and a high intake of cereal fibre has consistently been associated with a lower risk of diabetes (Willett *et al.* 2002). For example, in a large prospective study of more than 42 000 men followed for about 12 years, an inverse association was found between wholegrain intake and type 2 diabetes. After adjustment for confounding factors, men in the highest quintile of intake compared to those in the lowest had an RR of 0.58 (Fung *et al.* 2002). Similar results have been seen in women (*e.g.* Liu *et al.* 2000; Meyer *et al.* 2000). Montonen *et al.* (2003) studied the intake of wholegrain and fibre of over 4 000 Finnish men and women, and the subsequent incidence of type 2 diabetes during a 10-year follow-up. An inverse association was found between wholegrain intake and risk of type 2 diabetes, with an RR between the highest and lowest quartiles of wholegrain consumption of 0.65, *i.e.* a 42% reduction in risk. A reduced risk of type 2 diabetes was also associated with cereal fibre (RR 0.39). Data pooled from seven prospective cohort studies (including the Montonen study) provided a summary estimate of a 30% reduction in risk (RR 0.70) (Liu 2003). In this paper the author highlights the need to distinguish between the biological effects of wholegrain and those of refined-grain products, to help clarify the message that should be communicated to the public.

Several studies have also shown an inverse relation between GI/GL and risk of developing diabetes, for example:

- The Nurses Health Study found for comparing highest GI with lowest GI, the RR of developing diabetes was 1.37. The GL was also associated with diabetes (RR 1.47), and a high GL combined with a low cereal fibre intake (< 2.5 g/day) increased the risk of diabetes further (RR 2.50) (Salmeron *et al.* 1997a).
- Similarly, in the Health Professionals' Follow-Up Study, men with a high-GI diet had an increased risk of diabetes (comparing the highest with the lowest quintile, RR 1.37). Those men with a high-GL diet and a low cereal fibre intake (< 2.5 g/day) had a further increased risk (RR 2.50 compared to men with a low-GL diet and high cereal fibre intake) (Salmeron *et al.* 1997b).

In contrast, The Iowa Women's Health Study, while demonstrating a negative association between cereal fibre intake and risk of diabetes, found no significant association between GI or GL and diabetes incidence (Jenkins *et al.* 2002). However, an elderly cohort was used in this study, which could have introduced selection bias (Augustin *et al.* 2002).

Management of diabetes Currently the evidence base is strong for the role of a high-carbohydrate high-fibre diet in improving glycaemic control for people with type 1 or 2 diabetes (Mann 2001) and a higher fibre intake has been associated with better glycaemic control in people with type 1 diabetes (Buyken *et al.* 1998). A recent RCT demonstrated that, in people with type 2 diabetes, a high-fibre diet (containing 25 g soluble fibre and 25 g insoluble fibre) could decrease blood glucose and insulin more than a diet of equivalent macronutrient and energy content, containing moderate amounts of fibre (Chandalia *et al.* 2000). It is worth noting that the amount of fibre used in this study (50 g) is high. The current UK recommendation for adults is 18 g a day and the average UK intake of fibre in 2000/2001 was 15.2 g for men and 12.6 g for women (Henderson *et al.* 2003a). Additionally, the method used for measuring fibre in the USA differs from that used in the UK (see section 3.5.1), making comparisons difficult.

There is also a role for low-GI foods in the management of diabetes. Medium-term studies have shown that improvements in glycaemic control can be seen when people with diabetes replace high-GI foods with low-GI foods, such as wholegrain, minimally refined cereal products (Willett *et al.* 2002). For example, a randomised, crossover study by Jarvi *et al.* (1999) demonstrated that a low-GI diet improved glycaemic control as well as decreasing LDL-C and normalising fibrinolytic activity compared to a high-GI diet, identical for macronutrient composition and amount of dietary fibre. Although long-term studies are required to establish the long-term consequences, the GI concept is often used when counselling people with diabetes.

3.4.5 Digestive health

Insoluble fibre, which is found in a range of foods including cereals, may be important for gut health. Insoluble fibre absorbs fluid, increasing stool weight. It also promotes the growth and activity of the gut bacteria, which could also be beneficial for gut health. Recently, a small study demonstrated that moderate intakes of high-fibre wheat and high-fibre rye foods could improve other markers of gut health, such as decrease faecal beta-glucoronidase, secondary bile acids and para-cresol concentrations, and decrease faecal pH, compared with a low-fibre diet (McIntosh *et al.* 2003).

From their work in Africa, Burkitt and Walker suggested the importance of dietary fibre for digestive health, and a role in particular for preventing colorectal cancer. The World Cancer Research Fund currently lists NSP/fibre as a possible factor in decreasing the risk of colorectal cancer (World Cancer Research Fund 1997), although a UK report concluded that there was moderate evidence that diets rich in fibre would reduce colorectal cancer (Department of Health 1998). Since this report several other studies have been published. A study of ~455 000 older women with relatively low fibre intake followed for a mean of 8.5 years found little evidence that dietary fibre intake lowered the risk of colorectal cancer. However, this study was set up to investigate breast cancer and not colorectal cancer, and the highest quintile only had an average fibre intake of ~17 g a day (Mai *et al.* 2003).

Two more recent studies have investigated the intake of dietary fibre and the incidence of colorectal cancer. The European Prospective Investigation into Cancer and Nutrition (EPIC) study followed more than 50 000 subjects aged 25–70 years for almost 2 million person-years. An inverse relationship between dietary fibre in foods and incidence of large bowel cancer was found, with an adjusted RR in the highest *vs.* lowest quintile of fibre from food of 0.58 (0.41–0.85). No food source of fibre was found to be significantly more protective but the results suggested that in populations with a low average intake of dietary fibre, doubling of total fibre intake from foods could reduce the risk of colorectal cancer by 40% (Bingham *et al.* 2003). Another study performed within the Prostate, Lung, Colorectal, and Ovarian Cancer Screening Trial found high intakes of dietary fibre were associated with a lower risk of colorectal adenoma, those in the highest quintile having a 27% decrease in risk compared to those in the lowest quintile. Fibre from cereals and from fruits showed the strongest inverse association (Peters *et al.* 2003). Intakes in the highest quintiles of these tow studies were more than 30 g of fibre a day, at least double the current average UK intake. The results from these last two studies are in contrast to those of a review of RCTs in this area which found no evidence to suggest that increased dietary fibre would reduce the incidence or recurrence of adenomatous polyps within a 2–4-year period (Asano & McLeod 2002).

The role of fibre in the treatment of other bowel problems has been investigated. The faecal bulking action of insoluble fibre makes it useful in the treatment of constipation and diverticular disease (Thomas 1994). In the past, a high-fibre diet was the normal treatment for irritable bowel syndrome, but a recent review by Burden (2001) revealed a move-away from this approach, towards manipulation of the fibre fractions in the diet, dependent on the individual's symptoms.

3.4.6 Other cancers

Fibre may also decrease the risk of pancreatic and breast cancer (WCRF 1997). A series of case–control studies in Italy found an inverse association between wholegrain food intake and the risk of a range of cancers, including those of the upper gastrointestinal tract, the bladder and the kidney (La Vecchia *et al.* 2003). Cereals may have a protective effect on hormone-related cancers because of their lignan content (Goldberg 2003). Lignans, a type of phytoestrogen, are modified by gut bacteria to be more similar in structure to mammalian lignans (Truswell 2002).

3.4.7 Hypertension

Hypertension or high blood pressure (defined in the guidelines of the European Society of Hypertension as >140/90 mmHg) is a major risk factor for CVD and renal disease (Hermansen 2000). Changes in sodium intake have been shown to affect blood pressure in older people and those with hypertension and diabetes, but more recently a food-based approach has been investigated. The Dietary Approaches to Stop Hypertension (DASH) studies focused on increasing consumption of a range of foods including wholegrain cereals, but with particular emphasis on fruits and vegetables, and low-fat dairy products. The DASH diet demonstrated a strong effect on hypertension, with a decrease in systolic blood pressure (SBP) of 11.4 mmHg and in diastolic blood pressure (DBP) of 5.5 mmHg among those hypertensive subjects ($n = 133$) (Appel *et al.* 1997). The benefits seen with the DASH diet may in part be due to its high fibre content, and several studies have specifically looked at the effect of fibre on blood pressure, for example:

- In a double-blind RCT, dietary fibre given as a supplement (7 g/day) was found to significantly reduce DBP among hypertensive patients ($n = 32$) compared to those receiving a placebo ($n = 31$) (Eliasson *et al.* 1992).
- A pilot RCT involving 18 hypertensive patients found the addition of 5.52 g beta-glucan/day decreased SBP by 7.5 mmHg and DBP by 5.5 mmHG. Virtually no change was seen in the control group (Keenan *et al.* 2002).
- Another small RCT study of hypertenisve patients ($n = 88$) found that by including a wholegrain oat cereal, more patients in the oats group could stop or reduce their anti-hypertensive medication (77% *vs.* 42%). Those in the oat group whose medication was not reduced had substantial decreases in blood pressure, suggesting that wholegrain oats can have a beneficial effect on blood pressure (Pins *et al.* 2002).

Although the exact effect (if any) of fibre and/or cereals on blood pressure is not known, current recommendations encourage a whole-diet approach, along with lifestyle modifications such as achieving a healthy weight, regular physical activity, limiting alcohol intake, stop smoking and being physically active. In addition to helping control blood pressure, these recommendations will have a wide range of beneficial effects on other areas of health.

3.4.8 Food intolerance and allergy

There are hundreds of different foods which may cause adverse reactions in certain individuals and cereals containing gluten (defined currently by the EU to include wheat, rye, barley, oats and spelt or their hybridised strains) are recognised as one of the more common causes of intolerance (Buttriss 2002).

A specific intolerance to gluten can cause coeliac disease, which leads to inflammation of the small intestine and malabsorption. In the past the prevalence of coeliac disease in the UK has been estimated at 1 case in 1 500 people. However, the use of serological screening tests suggests the true prevalence may be higher – a study in Belfast has suggested a prevalence of 1 in 130 (Buttriss 2002). Traditionally, wheat, rye, barley and oats and products containing these cereals have been avoided. However, recently a small study of 15 coeliac disease patients in remission, who included large amounts of oats in their diets, found no adverse effects over a 2-year period (Størsrud *et al.* 2003). Similarly, work by Janatuinen *et al.* (2002) also found that there were no significant differences in people with coeliac disease between those consuming oats for 5 years and controls. Although contamination of oats with wheat, rye and barley during harvesting, transportation and milling is possible, several studies have reported no effects of trace amounts of gluten, either to the small intestine mucosa or gastrointestinal symptoms.

3.5 Labelling and health claims

3.5.1 Labelling

In the UK, nutrition labelling is not mandatory but if a claim is made nutrition information must be given. The two current formats are the Group 1 declaration (energy, protein, carbohydrate and fat) and Group 2 (as for Group 1 plus sugar, saturates, fibre and sodium). In the UK the Englyst method, which measures only the NSP component, has been used to calculate the fibre content of foods. Other EU countries and the USA use the American Association of Analytical Chemists (AOAC) method, which also measures lignin and resistant starch, leading to a higher value when compared with that found using the Englyst method. In December 2000, the Food Standards Agency issued a notice to inform the food industry that the AOAC method would now be used in order to harmonise free trade.

With regard to ingredient labelling, an amendment has been agreed to the EU Directive on food labelling (2000/13/EC). This will require common foods and ingredients causing allergic reactions to be labelled – currently some exemptions exist. Cereals containing gluten, *i.e.* wheat, rye, barley, oats (although this may change due to new research that is emerging, such as that mentioned in section 3.4.7), spelt or their hybridised strains, and products derived from these foods, will be included in this proposal.

The GI concept (discussed in earlier sections) has been used in the management of diabetes in a number of countries, including Australia where they have developed licensed GI labelling on pre-packaged foods (Nantel 2003). There are several methodological considerations in determining the GI of a food, *e.g.* the rise in blood glucose is highest at breakfast (after a 10–12-h overnight fast) and there is variability within and between subjects (so tests should be repeated three times with each subject to obtain a representative mean). However, there is interest in bringing this concept into a UK public health context and several laboratories will soon offer GI testing.

3.5.2 Health claims

As more is learnt about diet and health, there is an increased need and justification to communicate positive health messages, and health claims are one method that may be used. Although legislation specifically covering health claims does not currently exist in the UK, in the USA, where there is such legislation, currently approved claims include those associating:

- soluble fibre from certain foods and the risk of CHD;
- diets low in saturates and cholesterol and high in fruits, vegetables and grain products that contain fibre, particularly soluble fibre, with reduced risk of heart disease.

In Sweden, eight generic relationships have been recognised including constipation and dietary fibre, and soluble fibre and blood cholesterol. In 2002, the UK Joint Health Claims Initiative approved a claim for wholegrain foods and heart health ('people with a healthy heart tend to eat more wholegrain foods as part of a healthy lifestyle'), with wholegrain foods defined as those containing 51% or more wholegrain cereals.

EU legislation on health claims has been proposed which potentially will limit the types of foods that will be allowed to carry claims. As well as prohibitions on non-specific claims, claims regarding psychological and behavioural functions and health claims on alcohol, the proposal outlines plans to evaluate the 'nutritional profiles' of foods, with a view to restricting the use of claims on some foods with high fat, high salt and/or high sugar contents. A pre-approval process is planned, which will require submission of a dossier containing relevant scientific evidence, prior to approval of a health claim (further information can be found at http://europa.eu.int/prelex/detail_dossier_real.cfm?CL=en&DosId=184390).

3.6 Consumer understanding

Generally it appears that many consumers believe their diet is healthy. For example, in an EU survey, 71% of respondents thought they had no need to change what they were eating. Additionally, almost half of people did not think about the nutritional aspects of the foods they eat (Kearney *et al.* 1997). It seems that nutrition/healthy eating does not have a top priority for some people (Kearney *et al.* 2000). Although the UK has no specific recommendations for servings of wholegrain foods per day, evidence from dietary surveys suggests intakes are low. For example, about 30% of UK adults had no wholegrain foods during the period of survey (1 week) and over 97% did not meet the US recommendation of three servings per day (Lang & Jebb 2003). It has been suggested that some consumers may find it difficult to identify wholegrain foods; some people believe they do not have the necessary skills to prepare and cook wholegrain foods while others think wholegrain foods may be bland and dry tasting (Lang & Jebb 2003).

Work in Australia found that the relationship between fibre intake and its food sources was relatively well understood, although confusion still existed about specific food sources of fibre (Cashel *et al.* 2001). However, it has been shown that it is possible to change consumers' purchasing habits through health promotion. An advertising campaign in the USA highlighting the possible benefits of a high-fibre, low-fat diet in preventing some types of cancer increased the purchase of high-fibre cereal (Levy & Stokes 1987).

There appears to be a belief among some members of the public that carbohydrate-based foods, such as cereals, are high in energy and 'fattening', while other individuals see these foods as nutritious and good for health (Stubenitsky & Mela 2000). High-protein, low-carbohydrate diets are growing in popularity and, although short-term weight loss may occur, this is most likely because of decreased energy intake. There is a lack of information regarding the long-term effects of carbohydrate restriction and health professionals have expressed concerns for people with underlying health problems (*e.g.* CVD, type 2 diabetes and those with impaired liver and kidney function) (Stanner in press).

In the UK, there appears to be a misconception regarding the incidence of allergy and intolerance, including cereals such as wheat, with many more people believing themselves to have a problem than the evidence would suggest. For example, one survey found that 20% of adults believed they had a food intolerance while in reality food intolerance in total is estimated to affect 5–8% of children and 1–2% of adults, while the prevalence of food allergy is estimated to affect 1–2% of children and less than 1% of adults (Buttriss 2002).

3.7 Key points

• Cereals have been part of the human diet since prehistoric times. They are staple foods, and cereals and cereal products are an important source of energy, carbohydrate, protein and fibre. They also contain a range of micronutrients such as vitamin E, some of the B vitamins, sodium, magnesium and zinc. Because of the mandatory fortification of some cereal products (*e.g.* white flour and therefore white bread) and the voluntary fortification of others (*e.g.* breakfast cereals), they also contribute significant amounts of calcium and iron. There is growing interest in the phytochemicals cereal foods contain and the potential health benefits these substances may provide.
• There is evidence to suggest that regular consumption of cereals, specifically wholegrains, may have a role in the prevention of chronic diseases. The strength of evidence varies and although cause and effect has not currently been established, people who consume diets rich in wholegrain cereals seem to have a lower incidence of many chronic diseases. It remains to be established whether this is a direct effect, or whether wholegrain consumption is merely a marker of a healthy lifestyle.
• The exact mechanisms by which cereals convey beneficial effects on health are not clear but it is likely they are multifactorial and may be related to their micronutrient content, their fibre content and/or their GI.
• As there may be a number of positive health effects associated with eating wholegrain cereals, encouraging their consumption seems a prudent public health approach. However, as cereals and cereal products contribute a considerable proportion of the sodium intake of the UK population, manufacturers need to continue to reduce the sodium content of foods such as breakfast cereals and breads where possible.
• Nutrition labelling is currently not mandatory in the UK, although many manufacturers provide information voluntarily. The fibre content of most UK foods is still measured by the Englyst method rather than the AOAC method used by other EU countries and the USA and now recommended by the UK's Food Standards Agency. Currently, UK recommendations for fibre intake relate to the Englyst method, and hence need revision. Changes to EU labelling regulations will see the labelling of common foods and ingredients causing allergic reactions, including cereals containing gluten, and the introduction of EU legislation covering health claims may help consumers identify foods with proven health benefits.
• Several misconceptions exist among the public with regard to cereals and cereal products. Firstly, many more people believe they have a food intolerance or allergy to these foods than evidence would suggest and, secondly, cereals are seen by some as 'fattening'. The public should not be encouraged to cut out whole food groups unnecessarily. As cereals and cereal products provide a range of macro- and micronutrients, eliminating these foods without appropriate support and advice from a state-registered dietitian or other health professional could lead to problems in the long term.

4 Future developments

With advances in technology, there are now a number of ways in which cereals and their products can be enhanced. Traditional plant breeding is still an important tool [*e.g.* breeding for improved selenium uptake and/or retention (Lyons *et al.* 2003)], but it is also possible to change the nutrient content of cereal products through fortification and through genetic manipulation of the crop. Further research into the processing of cereals and production of cereal products may also improve overall nutrient content. Another area of interest is the interaction between genes and nutrients (see section 4.3). While technology may provide opportunities, it is important to consider the long-term consequences and consumer acceptability of new technology.

4.1 Fortification

As discussed earlier in section 3.3, flour (except wholemeal) in the UK is fortified with calcium, iron, thiamin and niacin. A number of other cereal products are fortified voluntarily, with the best example being some breakfast cereals which are fortified with a range of B vitamins, vitamin D, iron, vitamin C, vitamin E, beta-carotene and zinc (Buttriss 1999). Although some other cereal products are fortified with folic acid (the man-made form of the B vitamin folate), cereal products in America have been fortified with folic acid by law since 1997 and, recently in the UK, there has been debate regarding mandatory fortification of flour with folic acid.

Folic acid supplementation in the early weeks of pregnancy can protect against neural tube defects (NTD). All women of child-bearing age who may become pregnant are advised to take daily supplements (400 μg) of folic acid but in 2000/2001 more than 80% of this subgroup of the population had intakes from all sources below 400 μg (Henderson *et al.* 2003b). Additionally, many pregnancies are unplanned. Poor folate status is also associated with high homocysteine levels, an emerging risk factor for CVD, though it has yet to be demonstrated in RCTs that improvements in folate status reduce cardiovascular mortality. On the other hand, high intakes of folic acid may mask vitamin B_{12} deficiency, which causes a form of anaemia and is sometimes seen in elderly people. Estimates of vitamin B_{12} deficiency in the over 65s in the UK range from 1 in 500 to 1 in 15. If such a deficiency is not identified early enough then there is a possible risk of neurological damage. However, folate deficiency is also thought to be commonplace in elderly people (NDNS information from 1994/1995 found 1% of men and 6% of women aged 65 or older had inadequate folate intakes; Finch *et al.* 1998), posing a real dilemma for public health policy makers.

In America, rates of NTD births fell by 20% in 1 year and heart attacks among the elderly fell by 3.4% following folic acid fortification, but generally there is little evidence from other countries of the impact of folic acid fortification, especially on the prevalence of vitamin B_{12} deficiency. In 2000, the UK's Committee on Medical Aspects of Food proposed that flour be fortified with folic acid (240 μg folic acid/100 g flour) (Department of Health 2000). In 2002, after wide consultation, the Food Standards Agency decided against recommending mandatory fortification. As more information becomes available especially on the risk to those groups with low vitamin B_{12} status and the benefits for pregnant women and possible heart health benefits, this area should be revisited.

4.2 Genetic modification

As well as the possibility of manipulating the expression of native genes for disease resistance, novel genes may also be used, *e.g.* using virus-derived sequences to develop virus-resistant plants. It is also possible to develop transgenic cereals with resistance to herbicides, decreasing the need for herbicide use. Genetic modification also offers the possibility of improving the nutritional properties of cereals. Examples include increasing the oligosaccharide, polysaccharide and iron levels in cereals, enhancing vitamin E levels in corn and developing rice containing beta-carotene and rice containing iron (Henry 2001; Khush 2001; Lucca *et al.* 2002).

4.3 Gene–nutrient interactions

Some of the genes involved in the digestion and absorption of carbohydrate have been shown to be polymorphic or to show rare deficiency variants (*e.g.* glucose and galactose malabsorption due to lack of the appropriate transporter in the small intestine) (Swallow 2003). Although some single genes are being identified, the genetic component for chronic diseases such as type 2 diabetes, heart disease and obesity are mainly multifactorial (Williams 2003). For example, a subtype of type 2 diabetes has been associated with the genetic markers ADA and DS20S16 on chromosome 20q and abnormalities in the glucokinase gene on chromosome 7p. However, people without either of these genetic linkages can also have type 2 diabetes (Neel 1999).

As the knowledge base on gene nutrient interactions grows, it may be possible to target specific nutrition messages to people with specific genetic profiles, although such an approach is probably a way off, largely because of the complexity referred to above. With regard to research into nutrition and health, genetic variation is an important consideration and one that should be addressed in future studies. It has been suggested that genotyping of subjects in RCTs be performed prospectively, allocating subjects of each genotype randomly to each treatment (Mathers 2003). However, this will add to the complexity of the study, influencing recruitment, study length and cost.

4.4 Key points

- Fortification of white flour with folic acid (the man-made form of the B vitamin folate) has been proposed in the UK, to decrease the rate of NTD. Such a move could also have a benefit for heart health as poor folate status is associated with high homocysteine levels, an emerging risk factor for CVD. However, high intakes of folic acid can mask vitamin B_{12} deficiency a condition that occurs more frequently with age and has serious neurological symptoms affecting the peripheral nervous system.
- The disease resistance of cereal crops can be increased by manipulating the expression of native genes. Novel genes may also be used for this purpose as well as for developing cereals with resistance to herbicides, and cereals with improved nutritional properties (*e.g.* increased levels of iron and rice containing beta-carotene). The long-term consequences and consumer acceptability of such advances must be considered and consumer choice maintained.
- Knowledge of the interactions between genes and

nutrients continue to grow and in the future it may be possible to target specific nutrition messages to people with specific genetic profiles.

5 Conclusions and recommendations

Cereals have been a mainstay of the diets of people worldwide, since records began. Even with the diversity of foods now available, cereals remain a fundamental part of the dietary pattern, providing energy and fibre, and a range of nutrients, such as carbohydrate, protein, B vitamins, vitamin E, iron, magnesium and zinc. Fortified cereal products such as white bread and breakfast cereals are important sources of nutrients for both children and adults, although sodium levels of these and other processed cereal foods should continue to be reduced to help people to lower their overall sodium intake.

It is now recognised that cereals can also provide other bioactive substances, such as lignans, which may prove important for health. Further research is required in this area, including identification of other substances within cereals and their bioavailability.

Currently, most of the evidence for the health benefits of cereal foods relates to wholegrain foods and their fibre content and/or their low GI, although other factors may also be involved (*e.g.* resistant starch, micronutrients and bioactive substances in wholegrain cereals). To increase consumption of wholegrain foods, it may be useful to have a quantitative recommendation. Additionally, a wider range of wholegrain foods that are quick and easy to prepare would help people increase their consumption of wholegrain foods.

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Glossary

Caryopsis: the fruit of cereal, commonly referred to as the grain.

Conditioning: the use of heat in tempering.

Couscous: a food product prepared from wheat semolina (*T. durum*).

Decortication: also referred to as dehulling or dehusking; this process describes the complete or partial removal of the outer layers from grains (and seeds, fruits and nuts).

Embryo or germ: a thin-walled structure within the cereal grain, containing the genetic material for a new plant.

Endosperm: the main part of the grain, containing thin-walled cells packed with starch.

Fibre: a group of substances in plant foods which cannot be completely broken down by human digestive enzymes. In the UK the Englyst method has been used for determining the amount of fibre in food. This method measures only the polysaccahride component of dietary fibre, referred to as non-starch polysaccharides (NSP), and does not include lignin and resistant starch. Other countries and the USA use the American Association of Analytical Chemists (AOAC) method which also includes lignin and resistant starch.

Glume: an additional layer to the caryopsis, also referred to as the husk.

Glycaemic index (GI): used for classifying carbohydrate-containing foods, GI is the 'incremental area under the blood glucose curve after consumption of 50 g carbohydrate from a test food divided by the area under the curve after eating a similar amount of control food (generally white bread or glucose)' (Ludwig & Eckel 2002).

Glycaemic load (GL): assesses the total glycaemic effect of the diet and is the product of dietary GI and total dietary carbohydrate.

Goitrogen: substance that inhibits either the synthesis of thyroid hormones, or the uptake of iodine into the thyroid gland. Goitrogens can be found in food and can cause goitre when there is a marginal iodine intake.

Gristing: blending of grains prior to milling to produce a flour of the required quality.

Mycotoxin: toxic chemical substance produced by certain types of mould.

Pearling: A polishing process that removes the outer husk and part of the grain, leading to rounding of a cereal grain.

Phytochemicals: bioactive substances found in plants and plant-derived foods.

Relative risk (RR): used in epidemiology, it defines the likelihood of an adverse health outcome in people exposed to a particular risk, compared with people who are not exposed.

Resistant starch: starch that resists digestion and is only partially digested in the small intestine.

Temper: the addition of water to cereal grain prior to milling.

Wheat germ: the embryo of the wheat seed which is usually discarded when wheat is milled to white flour. Wheat germ contains most of the lipids of the wheat grain, most of the vitamin B_{12}, a quarter of the riboflavin and a fifth of the vitamin B_6.