nucleolus (the site of ribosomal RNA synthesis) are contained within the nuclear matrix, the nucleoplasm.

The organelles within a cell play vital metabolic roles. **Mitochondria** house the respiratory machinery that generates **ATP** by way of the citric acid cycle (tricarboxylic acid or Krebs' cycle) and associated electron transport chain (**aerobic respiration**). Plastids of several types may be present. Proplastids are precursors of several plastid types, which include chloroplasts, the site of photosynthesis, which are present in some developing seeds but do not contribute effectively to their carbon economy. **Fatty acids**, a component of lipids (**oils**, fats) are synthesized in plastids (no specific name given) in seeds (this occurs in chloroplasts in leaves), and **starch** is synthesized and stored in **amyloplasts**.

Microbodies (glyoxysomes) participate in lipid mobilization in germinated seeds, wherein the fatty acids are broken down and converted to a precursor of sugars. These microbodies are converted to peroxisomes in greening cotyledons where they play a role in photorespiration.

An extensive and versatile network of membranes, the endoplasmic reticulum, ER (endomembrane system) is present throughout the cytoplasm of a cell. In some regions it is associated with the protein synthesizing complex, the polyribosomes (polysomes), to form rough ER, and in other regions it is devoid of these (smooth ER). It participates in many cellular functions, including the synthesis, processing and sorting of proteins destined for secretion and storage, and in the modification of fatty acids and synthesis of lipids. The **oil** (fat, lipid) **body** or oleosome is formed directly from the ER, as are some protein bodies. ER has conveniently been classified into three types: nuclear envelope, smooth ER, and rough ER (to which are attached ribosomes, the site of protein synthesis), but additional domains are now recognized for the binding to other cell components, including mitochondria and the plasma membrane.

The Golgi apparatus (Golgi body, trans-Golgi network) is a distinct, stacked membrane system which is vital for the transport of molecules within and from a cell. *De novo* synthesized proteins can be directed to the vacuole for storage or the plasma membrane for secretion, for example. The Golgi apparatus is also the site of synthesis for cell wall hemicelluloses and pectin.

The vacuole is a fluid-filled compartment which is separated from the cytoplasm by a tonoplast membrane, which is similar to the plasma membrane. In the compact cells of seeds there are initially many small vacuoles which, following germination, may coalesce into one or a few large vacuoles. They are the site of storage of many molecules, including organic acids, amino acids, **phenolics**, sugars, enzymes, storage proteins and **phytin**. During seed development, as storage proteins and phytin are sequestered within a large vacuole, it fragments to become many small **protein bodies** (protein storage vacuoles, PSVs). (JDB)

Cellulose

An insoluble (homo)polymer of glucose which is a vital structural component of many **cell walls**; for exceptions **see: Hemicellulose.** It exists in microfibrils, which are paracrystalline assemblies of 36 parallel cellulose chains of β-1,4-linked glucose units, 2–3 μm long. Microfibrils are embedded in a **pectin** matrix and held in place in the cell wall by cross-linking hemicelluloses, **xyloglucans** (dicots), and glucuronoarabinoxylans or mixed linkage **glucans** (monocots).

Cellobiose is a β-1,4-linked dimer of glucose, and cellotriose a trimer.

Cereals

1. Introduction

Cereals are food plants belonging to the grass family, Poaceae (previously Gramineae), and are primarily cultivated for their grains (strictly **caryopses**). Cereal grains provide about half the energy consumed by humans worldwide; more if animal feed is taken into account. **See: Crop Atlas Appendix, Map 25**. The grains are starchy, dry and relatively low in oils, allowing for easy storage. The term **millet** is used for small-seeded cereals. **Pseudocereals** are food plants with similarly starchy seeds but which belong to other plant families.

2. Types

Of the approx. 10,000 species of grass, perhaps 50 are cultivated as cereals, and of these fewer than 12 qualify as major crops (Table C.5). The grass family is divided by taxonomists into 40 tribes; within each tribe, genera often share morphological and ecological characteristics and food properties. In general, the Triticeae, Aveneae and Oryzeae account for the temperate cereals, which fail to thrive at high temperatures, while the other tribes contain tropical cereals (with the exception of **foxtail** and **proso** millet). Temperate cereals can be grown in the tropics, at high altitudes.

Selection and breeding has led to the production of a great number of cultivars of most of the cereals shown in Table C.5, to suit regional or local needs, of different composition and yield characteristics, disease resistance, etc.

3. Origins

Cereals were among the World's first crops (Table C.5): indeed, it is arguable that their use sustained the development of the various civilizations. In the Old World, **wheat** and **barley** originated and were domesticated by Neolithic peoples about 10,000 years ago in the 'Fertile Crescent' of the Near and Middle East. From these sites, the cereals spread throughout the Mediterranean and Eurasia, and shortly after, the other temperate cereals, oat and rye, came into use. Botany and archaeology place the origins of **rice** in China or India and there is evidence for domestication of the cereal in parts of China, India and Southeast Asia at times between about 6000 and 8500 years ago, although there are claims for this occurring up to 14,000 years ago in Korea. **Sorghum** and some of the millets originated in Africa where there is evidence of their use about 5000 years ago. **Maize** is thought to have originated in Mesoamerica 7000–10,000 years ago and there is evidence dating from 8000 years ago for its cultivation in ancient Central and South American civilizations. (**See: History of seeds in Mexico and Central America**)

4. Basic grain anatomy

The compound inflorescences of most grasses are made up of a number of **spikelets**, each consisting of one to several florets. A **floret** consists of two bracts (**palea** and **lemma**, the

Table C.5. The major cereals.

Tribe	Cereal	Domestication centre	Domestication time (est.)
Triticeae	**Wheat** (*Triticum* spp.) **Barley** (*Hordeum* spp.) **Rye** (*Secale cereale*)	Near East	10,000–11,000 ya
	Triticale	NA	NA
Oryzeae	**Rice** (*Oryza sativa*)	South China	8000 ya
	Red rice (*O. glaberrima*)	Africa (tropical)	?
	Wild rice (*Zizania palustris*)	North America	?
Aveneae	**Oat** (*Avena sativa*)	Near East (?)	3000–4000 ya?
Eragrostideae	**Finger millet** (*Eleusine coracana*)	East Africa	5000 ya (?)
	Teff (*Eragrostis tef*)	Ethiopia	?
Paniceae	**Foxtail millet** (*Setaria italica*)	Central Asia	7000 ya
	Proso millet (*Panicum mileaceum*)	Central Asia	7000 ya
	Pearl millet (*Pennisetum glaucum*)	West Africa	4000 ya (?)
	White fonio (*Digitaria exilis*)	West Africa	?
	Black fonio (*D. iburua*)	West Africa	?
Andropogoneae	**Maize** (*Zea mays*)	South Mexico	8000 ya
	Sorghum (*Sorghum bicolor*)	African savannah	?
	Job's tears (adlay) (*Coix lacryma-jobi*)	India?	?

Note: Cereals in bold lettering have separate entries. There are several other relatively minor or 'local' millets mentioned under **millets**. NA; not applicable, since this is a recent synthetic hybrid. ya: years ago.

latter in some cases extended into an **awn**), an ovary with two stigmas and three (in some cases, six) stamens. The base of the spikelet is subtended by other bracts, the **glumes**. Some grasses, such as maize and wild rice, have unisexual flowers located on different parts of the plant. After pollination and fertilization the ovary develops into the fruit enclosing the fertilized ovule, the seed. The fruit of a grass is a caryopsis: the single seed accounts for the greater part of the entire fruit when mature. The seed comprises the **embryonic axis**, **scutellum**, **endosperm**, **nucellus** and testa or **seedcoat**, and it is surrounded by the fruit coat or **pericarp**. The basic structural form of cereal caryopses is surprisingly consistent, to the extent that a generalized cereal grain can be described (Fig. C.5).

The embryonic axis has the potential to grow into a plant of the next (filial) generation. It is connected to and couched in the shield-like scutellum, which lies between it and the endosperm (see: **Embryo**, Fig. E.2). The scutellum behaves as a secretory and absorptive organ, serving the nutritional requirements of the embryonic axis. When germination occurs, exchange of water and solutes between the scutellum and starchy endosperm is extremely rapid, with secretion of hormones and enzymes and absorption of solubilized nutrients occurring across this boundary following germination. (See: **Mobilization of reserves – a monocot overview**)

The embryonic axis is well supplied with conducting tissues of a simple type and some are also present in the scutellum. The endosperm is of the same generation as the embryo and it comprises two clearly distinguished components: starchy endosperm and **aleurone layer** (sometimes referred to solely as aleurone). Starchy endosperm forms a central mass consisting of cells packed with nutrients, predominantly **starch** but also **storage protein**, that can be mobilized to support growth of the embryonic axis following germination. In all cereals there is an inverse gradient involving these two components, the protein percentage per unit mass of endosperm tissue increasing towards the periphery. Cell size also diminishes towards the outside and this is accompanied by increasing cell wall thickness. The walls of the starchy endosperm of wheat are composed mainly of arabinoxylans, while in barley and oats (1→3) and (1→4) β-D glucans predominate. Cellulose contributes little to cereal endosperm walls except in the case of rice. In most cases the

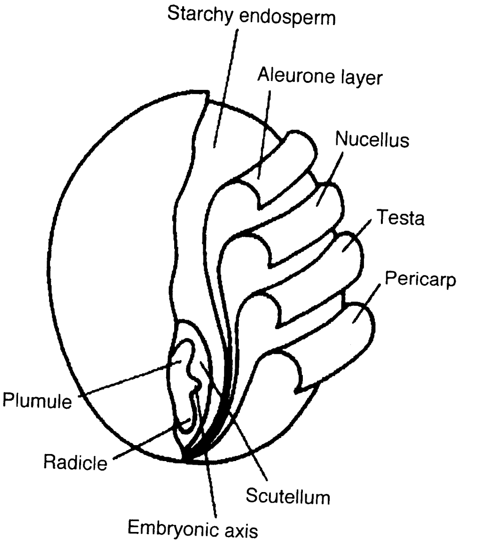

Fig. C.5. Structure of the cereal caryopsis, showing the tissue types that are present.

starchy endosperm cells are dead at seed maturity as the vital contents (membranes, nucleus, etc.) become disrupted by the accumulating reserves.

Surrounding the starchy endosperm cells, the aleurone layer consists of thick-walled cells with dense contents and prominent nuclei. Wheat, rye, oats, maize, rice and sorghum have an aleurone layer that is one cell thick (in the region adjacent to the conducting tissue the number of cell layers may be greater; in rice it can be to up to six) and in barley it is three cells thick. **Aleurone layer** cells contain no starch but they have high protein content, they are rich in oil, and contain **phytin**. When the seed germinates, hydrolytic enzymes responsible for solubilizing the reserves are synthesized in the aleurone layer cells of most cereal species. The balance between aleurone layer and scutellum in this role varies among species. A further function of some aleurone layer cells is the transfer of metabolites into the starchy endosperm during grain maturation. Though the starchy endosperm is non-living at maturity, the aleurone layer cells remain alive until well after the seed has germinated and is involved in reserve mobilization. (**See: Cereals – composition and nutritional quality**)

The nucellar epidemis, all that remains of the nucellus, surrounds the endosperm and embryo. In most cereals a cuticle is present on its outer surface. The nucellus, like all the tissues lying outside it, belongs to the current or parental generation.

The outermost tissue of the seed proper is the testa or seedcoat. It may consist of one or two cellular layers. In some varieties of sorghum a testa is absent altogether. Where two layers are present the long axes of their elongated cells lie at approximately 90° to each other. Frequently the cells of the testa accumulate corky substances during grain ripening and this may confer colour on the grain (e.g. red) and it reduces the permeability of the testa. A cuticle, thicker than that of the nucellar epidermis, is typical, and this also plays a role in regulating water and gaseous exchange.

The pericarp, or fruit coat, consists of several complete and incomplete layers. In all mature cereal grains, most cells in all pericarp tissues are dry and empty. With the seedcoat(s) (testa and nucellar epidermis) it protects the endosperm and embryo within against physical damage and fungal and insect attack. In certain types of sorghum some cells containing **starch granules** persist to maturity in the pericarp, but in most species both the granules and the cells in which they occurred during development are digested before maturity.

The outer epidermis has a cuticle that controls water relations in developing grains but this generally becomes leaky on drying. Hairs (**trichomes**) are present at the non-embryo end of wheat, rye, barley, **triticale** and oats. They are collectively known as the 'brush' and they have a high silicon content.

A summary of the presence or absence of individual covering layers showing the variation among species is given in Table C.6.

In some cereal grains, such as oats, barley and rice, the lemma and palea are usually closely adherent and are thus not removed by threshing; in other cereals (millets, oats) the lemma and palea are not adherent but are very rigid and do not fall off during threshing. These **hulls** (husks) are therefore part of the grain as traded, and their additional contribution to grain mass has to be borne in mind when comparing the relative proportions of nutrients in different species (Table C.7).

Cereals are attractive and important crops, particularly because of their large endosperm with its energy-rich storage reserves. The dry seed can be easily stored for long periods. The cereals have a naturally high fruit set so that yield potentials are favourable. Another important feature is that cereals are non-**shattering**, i.e. the mature fruits are not dispersed from the plants. This presumably was a tendency of the early domesticated types that was increasingly selected, together with the potential towards high yields. (**See: Domestication; Yield potential**)

5. Production and economic importance

Three species accounted for 85% of the world's cereals in 2001: maize, rice and wheat (Table C.8). Since 1960, the

Table C.6. Tissue layers present in grains of different cereal caryopses.

	Fruit coats							
Cereal	Epidermis	Hypodermis	Intermediate layer	Cross cell layer[a]	Tube cell layer	Testa[a]	Nucellar epidermis	Aleurone layer[a]
Barley	+	+		2	+	1	+	2–4[d]
Maize	+	+		+	+	[b]	[b]	1
Proso millet	+	+		+	+	[b]	[b]	1
Oat	+	+				1	+	1
Rice	+	+		+	+	1	+	1–3[d]
Rye	+	+	+	+	+	2	+	1
Sorghum	+	+		+[c]	+	0	+	1
Triticale	+	+	+	+	+	2	+	1
Wheat	+	+	+	+	+	2	+	1

[a]Numbers indicate cell layers.
[b]A cuticular skin persists to maturity.
[c]Incomplete layer.
[d]In barley the variation is varietal, while for rice it occurs within a single grain. In rice, aleurone layers are more abundant in lowland than upland rice and generally less in *Indica* than *Japonica* type, but the number can increase in *Japonica* if night temperatures are high during histodifferentiation. (**See: Development of seeds – an overview**)

Table C.7. Grain weights and typical proportions (%) of grain parts in some cereals.

Cereal	Grain weight (mg)	Hull	Pericarp and testa	Aleurone layer	Starchy endosperm	Embryo	
						Embryonic axis	Scutellum
Naked grains							
Wheat	27–50	–	8.5	6.7	82	1.3	1.5
Maize	150–600	–	6.0	2.7	77.8	1.5	12.0
Rye	15–40	–	10.0		86.5	1.8	1.7
Sorghum	8–50	–	7.9		82.3	9.8	
Proso millet	n/a	16.0	3.0	6.0	70.0	5.0	
Hulled grains							
Rice	n/a	20.0	4.8 (6.0)		72.7 (90.9)	1.0 (1.2)	1.5 (1.9)
Barley	32–36	13.0	2.9 (3.3)	4.8 (5.5)	76.3 (87.0)	1.7 (1.9)	1.3 (1.5)
Oats	n/a	25.0	9.0 (12.0)		63.2 (84.0)	1.2 (1.6)	1.6 (2.1)

Where cells are merged the number relates to the total value for the two tissues. Values for individual tissues were not found.
Values in parenthesis are proportions of grain excluding hull.
Based on information in Pomeranz, Y. (1998) Chemical composition of kernel structure. In: Pomeranz, Y. (ed.) *Wheat Chemistry and Technology*. American Association of Cereal Chemists, St Paul, MN, USA.

Table C.8. World production of cereals in 2001.

Cereal	Area harvested (million ha)	Yield (hg/ha)	World production	World production (%)	Export trade	Animal feed	Main countries of cultivation, with annual production
Barley	56.2	25.7	144.1	6.8	27.4	90.1	Russian Federation (19.5), Germany (13.5), Canada (10.9), Ukraine (10.2)
Fonio	0.355	7.2	0.257	0.01	–	–	Guinea (0.13), Mali (0.02)
Maize	139.1	44.2	614.5	29.2	81.6	407.0	USA (241.5), China (114.3), Brazil (41.4), Mexico (20.1)
Millets	37.0	7.9	29.1	1.4	0.249	2.6	India (11.4), Nigeria (5.5), Niger (2.4), China (2.0)
Oats	13.2	20.6	27.2	1.3	3.3	19.7	Russian Federation (7.7), Canada (2.7), USA (1.7)
Rice, paddy	151.2	39.5	597.8	28.4	41.2	10.2	China (179.3), India (139.7), Indonesia (50.5), Bangladesh (36.3)
Rye	9.9	23.6	23.3	1.1	1.6	10.9	Russian Federation (6.6), Germany (5.1), Poland (4.9)
Sorghum	44.2	13.5	59.5	2.8	7.0	29.4	USA (13.1), India (7.8), Nigeria (7.1)
Triticale	2.9	35.9	10.4	0.5	–	–	Germany (3.4), Poland (2.7), France (1.1)
Wheat	214.8	27.5	590.5	28.0	134.0	102.4	China (93.9), India (69.7), USA (53.3), Russian Federation (47.0)
Other	–	–	10.2	0.5	–	–	–
TOTAL	676.6	–	2106.9	–	–	–	–

Source: FAOSTAT (http://apps.fao.org/). Figures are in millions of tonnes unless otherwise stated.

'Green Revolution' combination of plant breeding and higher inputs of irrigation and fertilizers has enabled world production to keep pace with population; overall production of these three cereals has nearly tripled (from 640 million t in 1961 to 1800 million t in 2001), with only a 20% increase in the area cultivated. Production of these major cereals is linked to complex patterns of government subsidies and world trade. Minor cereals, such as the African millets, are being rapidly replaced by the major cereals, particularly maize, in tropical countries. However, minor cereals are now recognized as being of local importance, particularly because of their adaptation to poor, dry soils, and plant-breeding efforts are increasing in this area.

Production and consumption of cereals within individual countries and continents are not matched and movements of cereal grains contribute significantly to world trade. In 2001 the value of the world trade in cereals was approximately US$ 40 billion. Trade overall, and in the case of individual countries, is influenced by commodity price, which can be influenced by supply and demand. Annual surpluses of cereals might be stored for following seasons because harvests are subject to variation due to climatic conditions and decisions by growers as to the area planted. Also, trading is highly sophisticated and importing nations source their supplies according to supply and price at the time of need. Consequently, trading patterns at any time give only a poor indication of events before and after the time of reporting. Table C.9 reflects the position for those cereals that contribute in a major way to world trade during the 2002/3 season. (See: **Crop Atlas Appendix, Maps 1, 5, 6, 7, 8, 9, 10, 11, 12, 21, 23, 24**).

6. Grain quality

'Quality' in the general sense means 'suitability for a particular purpose'. As applied to cereals, the criteria of quality may be described in terms of: (i) *yield* (of grain for the grower; of high value components for the primary processor, and of final product for the end user); (ii) *ease of processing*; nature of the resulting end product: uniformity, appearance, chemical composition, and in the case of food and feed products: wholesomeness and palatability.

These criteria of quality are dependent upon the variety of cereal grown and upon environment, climate, soil and manure or fertilizer treatment. Manner of harvesting and storage also exert a profound influence on grain quality. Grain exposed to wet conditions before harvest may exhibit signs of germination being completed, such as high content of hydrolytic enzymes or, in extreme cases, sprouting of shoot and roots from the embryo. High enzyme production is undesirable, particularly for breadmaking. The enzyme of most concern is α-amylase, because conversion of starch to sugars in the dough gives rise to heavy, sticky bread, which is difficult to slice. (See: **Pre-harvest sprouting**)

Drying the grain before or during storage can also cause deterioration. Safe drying temperature declines at higher moisture contents. Use of excessive temperatures reduces germinability and denatures proteins important for subsequent processing. Some of the hazards encountered during storage are discussed in **Cereals – storage** and **Storage Management**.

Because of the many uses to which cereals are put, there are many different perceptions of quality, for example, in the case of wheat, a baker and his customers are likely to be interested in baking properties while a stock feeder will be concerned with nutritional properties. To a minority of end users who demand organically grown crops the manner of crop production and storage is the major quality requirement. Others may impose equally strong conditions for exclusion of products from genetically modified plants.

For marketing purposes it has been customary for many years to grade cereal samples according to certain criteria but the number of these is, of necessity, restricted and incapable of covering requirements for all end-uses. Most grading systems employ a system of segregation by class as well as by grade. Distinction of wheat by class may be based on grain colour, endosperm texture and growing season, as in the USA grading system for common wheat (classes are defined as hard red spring, soft white, etc. and must include only cultivars accepted within the respective categories), or grain length, as in the USA rice grading system. In general, achievement of a grade depends upon conformity to the description of the class, freedom from contamination by damaged, shrivelled, sprouted and diseased grains, fruits (seeds) of non-conforming plants, soil and other foreign matter. Within a class, grades may be defined by protein content and quality, and bulk density. Although fairly consistent, the grade limits may be changed from year to year, according to the quality of the harvest.

Competition among cereals merchants as well as exporting countries has led to a move away from rigid classification, towards greater flexibility aimed at meeting precise requirements of purchasers. For many end-uses, measurable criteria cannot fully define requirements so specification of variety required or to be excluded is specified in purchase orders.

7. Primary processing

For humans and most other animals to digest the nutritional parts of cereals, grains are best initially ground. Often, a further cooking stage is required before digestion can be achieved. Most types of primary processing involve reduction in particle size. Some include chemical treatment (e.g. maize).

Table C.9. Weights of major cereal grains traded in 2002/3 season (tonnes × 1000).

Wheat		Maize		Rice (2002 calendar year)		Barley		Sorghum	
Total World Trade 107,800		Total World Trade 77,960		Total World Trade 27,880		Total World Trade 16,090		Total World Trade 5830	
Exporters									
USA	22,970	USA	41,000	Thailand	7,245	EU	5,000	USA	4,900
EU	16,000	China	15,240	India	6,650	Russia	3,200	Argentina	600
Russia	12,620	Argentina	12,500	USA	3,295	Ukraine	2,300	Sudan	190
Australia	10,950	Brazil	3,200	Vietnam	3,245	Australia	2,200		
Canada	9,390	Hungary	1,500	China	1,960	Turkey	700		
Importers									
EU	12,000	Japan	16,500	Indonesia	3,500	Saudi Arabia	6,000	Mexico	3,400
Brazil	6,630	S Korea	8,790	Nigeria	1,820	China	1,790	Japan	1,500
Egypt	6,300	Mexico	5,500	Philippines	1,250	Japan	1,300	EU	400
Algeria	6,000	Egypt	5,000	Iraq	1,180	EU	700		
Japan	5,580	Taiwan	4,800	Saudi Arabia	940	Jordan	500		

Values ex *World Grain* sourcing from International Grains Council London, and United States, Department of Agriculture's Foreign Agricultural Service. Washington, D.C.

Cereal grains are harvested and may be stored, after which they are subjected to cleaning and processing. The products may be further processed; for example, wheat flour may be processed into bread or other baked products, but in this Encyclopedia we confine consideration to the first or primary processing and this usually involves treatments described as milling. Although the single term is applied, it does not necessarily involve the same treatment or series of treatments. For example, wheat is milled into a fine powder while rice milling results in whole endosperms with the outer tissues removed. Milling carried out in the presence of more water than can be absorbed by the grains is described as wet milling. Dry milling may involve the addition of water to grain to improve its behaviour during grinding but the amount of water added is well below that which can be absorbed by the grain tissues. One type of primary processing that involves water but no milling is **malting**, in which water is added to initiate processes associated with germination.

Because there are many different processes described as milling, it is best to consider the different types of milling separately. (AE, MN)

(See the individual entries for the following cereals: **Barley, Einkorn, Emmer, Finger Millet, Foxtail Millet, Job's Tears (Adlay), Maize, Oats, Pearl Millet, Proso or Common Millet, Rice, Rye, Spelt, Teff, Triticale, Wheat, Wild rice**; See: **Cereals – composition and nutritional quality; Cereals – storage**)

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Cereals – composition and nutritional quality

1. Composition and quality

Composition of grains in individual species of cereals can vary and also values for the same constituent are to some extent dependent on the analytical method used. Hence there are no absolute values for composition. The values for the main constituents of grains thus have only a comparative significance. Table C.10 is provided for this purpose.

The main contribution that all cereals make to diet is the carbohydrate **starch**, which can account for more than 70% of total dry mass of grains. It is a major source of energy. For human nutrition it is now widely recognized that, where choice is available, cereal products, vegetables (including potatoes) fruit and pulses, should provide approximately 55–60% of a healthy diet, and complex carbohydrates (starch) should contribute 40–50% of the total kilojoules consumed.

Different chemical components of cereal grains are distributed differentially. Most of the protein, for example, is in the **endosperm**, but some is in the **embryo** and the **aleurone layer** tissue. Moreover, the parts differ as to the types of protein they contain. Prolamins, glutelins and albumins are in most cases found in the starchy endosperm, and globulins in the embryo and aleurone layer (**see: Osborne fractions; Storage proteins**). Since these proteins differ in their nutritional value the nutritional qualities of the different parts must also differ. The prolamins, which in most cases are the dominant endosperm proteins, are deficient in lysine, threonine and tryptophan and some other **essential amino acids** (see below). Although the aleurone layer and embryo are proportionately rich in proteins, especially globulins, compared with the starchy endosperm, these tissues have little impact on overall nutritional properties of the grain since in most cereals prepared for human consumption the aleurone layer and embryo account only for a small fraction of grain mass and in any case are usually removed during grain

Table C.10. Approximate analysis of cereal grains (and products if data for grains are unavailable).

Cereal grain or product	Moisture	Protein	Oil	Carbohydrate*	Fibre†
Barley – whole grain	11.7	10.6	2.1	64.0	14.8[a]
– pearl, raw	10.6	7.9	1.7	83.6	5.9[b]
Foxtail Millet – flour	13.3	5.8	1.7	75.4	
Maize – whole	15.5	11 0	5 0	65 0	
Oats – oatmeal raw	8.9	12.4	8.7	72.8	6.3[a] 6.8[b]
Rice – brown	13.9	6.7	2.8	81.3	3.8[a] 1.9[b]
– white	11.4	7.3	3.6	85.8	2.7[a] 0.4[b]
Rye flour – whole	15.0	8.2	2.0	75.9	11.7[b]
Sorghum	15.5	11.2	3.7	74.1	2.6[c]
Triticale	10.5	13.05	2.09	72.13	2.6[c]
Wheat – wholemeal	14.0	12.7	2.2	63.9	8.6[a] 9.0[b]

*Mostly starch.

†Superscript letters indicate different methods of determination.

Values are per cent fresh weight (in the cases of whole grains).

The Encyclopedia of Seeds
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