Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

23-May-2003

English - Or. English

ENVIRONMENT DIRECTORATE
JOINT MEETING OF THE CHEMICALS COMMITTEE AND
THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY

Series on the Safety of Novel Foods and Feeds, No. 7

CONSENSUS DOCUMENT ON COMPOSITIONAL CONSIDERATIONS FOR NEW VARIETIES OF BREAD WHEAT (Triticum aestivum): KEY FOOD AND FEED NUTRIENTS, ANTI-NUTRIENTS AND TOXICANTS

JT00144952

Also published in the Series on the Safety of Novel Foods and Feeds:

No. 1, Consensus Document on Key Nutrients and Key Toxicants in Low Erucic Acid Rapeseed (Canola) (2001)

No. 2, Consensus Document on Compositional Considerations for New Varieties of Soybean: Key Food and Feed Nutrients and Anti-nutrients (2001)

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No. 4, Consensus Document on Compositional Considerations for New Varieties of Potatoes: Key Food and Feed Nutrients, Anti-Nutrients and Toxicants (2002)

No. 5, Report of the OECD Workshop on the Nutritional Assessment of Novel Foods and Feeds, Ottawa, February 2001 (2002)

No. 6, Consensus Document on Compositional Considerations for New Varieties of Maize (*Zea mays*): Key Food and Feed Nutrients, Anti-Nutrients and Secondary Plant Metabolites (2002)

OECD Environmental Health and Safety Publications

Series on the Safety of Novel Foods and Feeds

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Consensus Document on Compositional Considerations for New Varieties of Bread Wheat (*Triticum aestivum*): Key Food and Feed Nutrients, Anti-nutrients and Toxicants

Environment Directorate

Organisation for Economic Co-operation and Development

Paris 2003

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FOREWORD

The OECD's Task Force for the Safety of Novel Foods and Feeds decided at its first session, in 1999, to focus its work on the development of science-based ***consensus documents,*** which are mutually acceptable among member countries. These consensus documents contain information for use during the regulatory assessment of a particular food/feed product. In the area of food and feed safety, consensus documents are being published on the nutrients, anti-nutrients or toxicants, information of its use as a food/feed and other relevant information.

This consensus document addresses compositional considerations for new varieties of wheat by identifying the key food and feed nutrients, anti-nutrients and toxicants. A general description of these components is provided. As well, there is background material on the growing, processing and uses of wheat and considerations to be taken when assessing new wheat varieties.

Australia served as the lead countries in the preparation of this document.

The Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology has recommended that this document be made available to the public. It is published on the authority of the Secretary-General of the OECD.

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PREAMBLE

Food and feed products of modern biotechnology are being commercialised and marketed in OECD Member countries. The need has been identified for detailed technical work aimed at establishing appropriate approaches to the safety assessment of these products.

At a Workshop held in Aussois, France (OECD 1997), it was recognised that a consistent approach to the establishment of substantial equivalence might be improved through consensus on the appropriate components (e.g., key nutrients, key toxicants and anti-nutritional compounds) on a crop-by-crop basis, which should be considered in the comparison. It is recognised that the components may differ from crop to crop. The Task Force therefore decided to develop consensus documents on compositional data. These data are used to identify similarities and differences following a comparative approach as part of a food and feed safety assessment. They should be useful to the development of guidelines, both national and international and to encourage information sharing among OECD Member countries.

These documents are a compilation of current information that is important in food and feed safety assessment. They provide a technical tool for regulatory officials as a general guide and reference source, and also for industry and other interested parties and will complement those of the Working Group on Harmonisation of Regulatory Oversight in Biotechnology. They are mutually acceptable to, but not legally binding on, Member countries. They are not intended to be a comprehensive description of all issues considered to be necessary for a safety assessment, but a base set for an individual product that supports the comparative approach. In assessing an individual product, additional components may be required depending on the specific case in question.

In order to ensure that scientific and technical developments are taken into account, Member countries have agreed that these consensus documents will be reviewed periodically and updated as necessary. Users of these documents are invited to provide the OECD with new scientific and technical information, and to make proposals for additional areas to be considered. ***A short, pre-addressed questionnaire is included at the end of this document. The information requested should be sent to the OECD at one of the addresses shown.***

THE ROLE OF A COMPARATIVE APPROACH AS PART OF A SAFETY ASSESSMENT

In 1990, a joint consultation of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) established that the comparison of a final product with one having an acceptable standard of safety provides an important element of safety assessment (WHO 1991).

In 1993 the Organisation for Economic Co-operation and Development (OECD 1993) further elaborated this concept and advocated the approach to safety assessment based on substantial equivalence as being the most practical approach to addressing the safety of foods and food components derived through modern biotechnology (as well as other methods of modifying a host genome including tissue culture methods and chemical or radiation induced mutation). In 2000 the Task Force concluded in its report to the G8 that the concept of substantial equivalence will need to be kept under review (OECD 2000).

The Joint FAO/WHO Expert Consultation on Foods Derived from Biotechnology in 2000 (FAO 2000) concluded that the safety assessment of genetically modified foods requires an integrated and stepwise, case-by-case approach, which can be aided by a structured series of questions. A comparative approach focusing on the determination of similarities and differences between the genetically modified food and its conventional counterpart aids in the identification of potential safety and nutritional issues and is considered the most appropriate strategy for the safety and nutritional assessment of genetically modified foods. The concept of substantial equivalence was developed as a practical approach to the safety assessment of genetically modified foods. It should be seen as a key step in the safety assessment process although it is not a safety assessment in itself; it does not characterise hazard, rather it is used to structure the safety assessment of a genetically modified food relative to a conventional counterpart. The Consultation concluded that the application of the concept of substantial equivalence contributes to a robust safety assessment framework.

A previous Joint FAO/WHO Expert Consultation on Biotechnology and Food Safety (1996) elaborated on compositional comparison as an important element in the determination of substantial equivalence. A comparison of critical components can be carried out at the level of the food source (i.e., species) or the specific food product. Critical components are determined by identifying key nutrients and key toxicants and anti-nutrients for the food source in question. The comparison of key nutrients should be between the modified variety and non-modified comparators with an appropriate history of safe use. The data for the non-modified comparator can be the natural ranges published in the literature for commercial varieties or those measured levels in parental or other edible varieties of the species (FAO 1996). The comparator used to detect unintended effects should ideally be the near isogenic parental line grown under identical conditions. While the comparative approach is useful as part of the safety assessment of foods derived from plants developed using recombinant DNA technology, the approach could, in general, be applied to foods derived from new plant varieties that have been bred by other techniques.

SECTION I – BACKGROUND

A. Production of Wheat[1]

1. Wheat is grown as a commercial crop in over 120 countries worldwide (FAO 2002), which makes it the most widely grown crop in the world today. World production and export figures for wheat are given in Table 1. China, the European Union (EU), India and the United States are the major wheat producers, accounting for nearly 60% of the total world production. The major wheat exporters, accounting for 86% of the total exports, are the United States, Canada, Australia, the EU and Argentina.

Table 1: Production and export figures for wheat

Country/Region	**Production (million tonnes)**		**Exports (million tonnes)**	
	2000	**2001 Estimate**	**2000/01 Estimate**	**2001/02 Forecast**
Argentina	16.0	15.5	11.0	11.0
Australia	23.8	23.3	16.5	18.0
Canada	26.8	21.3	16.8	16.0
China	99.6	94.2	0.4	0.3
European Community	105.2	92.0	14.5	11.0
India	75.6	68.5	2.3	2.5
Kazakhstan	9.1	13.5	3.7	4.2
Pakistan	21.1	19.0	0.3	1.0
Russian Federation	34.4	46.9	0.7	2.5
Turkey	18.0	16.0	1.6	0.4
Ukraine	10.2	21.3	0.1	4.5
United States	60.8	53.3	27.9	27.5
World total	598.3	591.1	100.4	106.0

(*Source*: FAO, February 2002)

B. Classification of Wheat

2. The commercially relevant crops of wheat are limited to four species of the genus *Triticum*. These are: *T. monococcum*, *T. turgidum*, *T. timopheevi*, and *T. aestivum*. Of these, *T. aestivum* and *T. turgidum* are the most widely grown. *T. aestivum* includes the common bread wheats and *T. turgidum* includes the durum wheats. This document only considers those constituents relevant to the common bread wheats.

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[1] For information on the environmental considerations for the safety assessment of wheat, see OECD Consensus Document on the Biology of *Triticum aestivum* (Bread Wheat). Series on Harmonisation of Regulatory Oversight in Biotechnology No. 9.

3. Extensive cultivation, breeding, and selection have resulted in many thousands of commercial varieties of bread wheats. This had led to yield improvement and to the development of wheats with the required milling and flour-processing qualities. For commercial purposes, the common wheats are classified into broad classes that are used as a basis of world trade. The major factors used to distinguish wheats are hardness or softness of the kernel, winter or spring growing habit, red or white seed coat, and protein content (Orth and Shellenberger 1988).

C. Uses of Wheat

4. Of the wheat that is produced in the world, about 74% is destined for human food use, 16% for animal feed use, 5.5% for seed, with the remaining 4.5% for use in industrial applications (International Grain Council 1996). As these figures show, the vast majority of wheat is used for human food, although it is also popular as an animal feed, particularly in years where there is a grain surplus and its price becomes competitive with other feed grains. The wheat plant is also popular as an animal feed where it is used for forage as well as hay and silage production.

D. Processing of Wheat

5. The processing of wheat can be divided into two categories: (i) dry milling; and (ii) wet milling with aqueous solvents. The two processes produce distinctly different products. In addition to the milling of wheat, wheat is also used in fermentation processes to produce industrial alcohol as well as beverages such as beer.

Dry Milling

6. The major products resulting from the dry milling of wheat are flour, bran and wheat germ. These products result from separating the grain (kernel) into its three distinct parts: the mealy or starchy endosperm (composed of the endosperm but lacking the aleurone layer), which is subsequently processed into fine particles (flour); the bran (composed of the pericarp, the seed coat and the aleurone layer); and the germ (composed of the embryonic axis and the scutellum). Wheat germ is further processed into wheat germ meal and oil. Wheat grains from current commercial varieties typically comprise about 2 – 3% germ, 13 – 17% bran and 80 – 85% mealy endosperm, on a dry matter basis (Belderok 2000).

7. Of the three major products resulting from the processing of wheat, flour is by far the most valued and versatile. Flour is used to produce a wide range of products, including pan bread, flat bread, noodles/pasta, cakes, pastries and biscuits.

8. The typical steps employed in the dry milling of wheat are shown in Figure 1. The objective during milling is to separate the bran and germ of the wheat kernel from the endosperm. Initial steps in the milling involve the cleaning and sifting of the grain. This is achieved using a separator, which is a series of screens that remove stones, sticks and other foreign material. From the separator, the wheat passes through an aspirator where jets of air remove many of the light impurities, such as dust and chaff. The next step involves a disc separator – the surface of the discs are indented so that wheat is caught but larger and smaller particles, such as foreign grains, are rejected. After passing through the disc separator, the wheat is scoured to remove the beard from the individual grains and passes through a magnetic separator to the washer-stoner (a machine that uses high speed rollers and water to remove stones). Prior to grinding, the cleaned wheat is tempered by adding water. This hydrates the outer bran coat, so that it becomes more elastic and will not splinter during grinding, and contaminate the flour, and also mellows the endosperm so that it breaks easily off the bran during grinding meaning less power is required to reduce large, pure

particles of flour. The tempered wheat passes into an Entoleter machine, which breaks and removes unsound wheat. The sound wheat then passes through a series of grinders, sifters and purifiers to separate the various parts of the grain. This process is repeated over and over again until the maximum amount of flour is separated.

9. None of the kernel fractions coming out of the mill are entirely pure, and each will contain some part of the other fractions. The level of purity of each product at the end of the process is one of the measures of milling efficiency. Generally, modern day millers remove about 80% of the wheat kernel for wheat flour, with the other 20% of the millstream going into the production of animal feeds as well as dietary fibre ingredients for human foods (Orth and Shellenberger 1988).

10. The remaining 20% of the millstream is known collectively as “millfeed”. Several different names, such as middlings, shorts, and red dog, have been assigned to various combinations of these millstreams but each name refers to a rather poorly defined material whose composition can be varied by changing roller settings, purification conditions and the way in which the millstreams are combined (Matz 1991). In some cases, all the non-flour streams are combined to yield a single product called “millrun”. Wheat middlings consists mostly of the layers of the wheat kernel just inside the bran, bran particles, some flour, and some non-wheat material. About 45% of the millfeed is middlings, the exact amount depending on the efficiency of the process, the type of wheat and the miller’s decision as to how the millstreams are to be combined. Wheat shorts typically contain more flour than do middlings and red dog contains more flour than the other millfeeds.

Wet Milling

11. Wet milling is the process used to separate starch from gluten, both of which are contained within the wheat endosperm. Wheat starch has physiochemical properties similar to cornstarch, although viscosity and gel strength are usually lower. When used in baking, it can replace portions of wheat flour, increase cake volumes and tenderness, and reduce fat absorption in doughnuts, as well as having applications in the confection and canning industries (Becker and Hanners 1991). Gluten is primarily used as an additive to improve the quality of flour for bread making (Matz 1991). Gluten is also used in hamburger buns and hot dog rolls to give the desired low density and texture. Small amounts of gluten are also processed into liquid dietary supplements and flavouring hydrolysates.

12. There are a number of different wet milling techniques that are used, with both the whole kernel and flour milling fractions able to be used as the starting material (Rao 1979). Whole wheat as the starting material has several advantages over flour milling fractions, including: it is a readily available raw material that is not tied to the supply of dry milled flour products; less starch damage can be expected because of the absence of the high shear effects of dry milling therefore yielding higher quantities of prime starch; and increased vitality in the gluten because the entire endosperm protein is recovered (i.e., including the gluten protein that would normally be ‘lost’ to the high quality patent flour) (Fellers 1973, Rao 1979).

13. The most well known method for separating starch from gluten, using flour as the starting product, is the Martin Process (Fellers 1973). It involves the continuous mixing of the flour with about 40 – 60% of its weight of water. The resulting dough is then washed in a continuous kneader with additional water, which washes away the starch, leaving a coherent mass of gluten. The starch milk is collected and passed through a centrifugal extractor fitted with special slotted screens to remove fibre and pentosan material. The starch milk is then concentrated, refined, washed and dried.

14. When whole wheat is used, the wheat is first tempered with water, and then flaked before further water is added to obtain hydrated dough. Separation of the dough is accomplished by washing with water

under high pressure. The starch, bran, germ and other non-gluten components are removed, leaving the hydrated elastic gluten. Vital gluten obtained after purification and drying contains about 75 – 80% protein.

Fermentation Processes

15. Although barley and corn grains are the most common substrates used for brewing and the production of industrial alcohol, respectively, a small amount of wheat is also used for these purposes (Wu 1989).

16. Wheat malt has only had limited use in the brewing industry, primarily because of its higher price but also because of the brewer's traditional preference for barley malt (Matz 1991). Despite this, a significant amount of wheat beers are brewed in Europe, with smaller amounts also being brewed in North America and Australia. Brewers' grains, which are typically a blend of the spent grain and hops, are one of the major by-products of the brewing process and are a popular feedstuff for cattle. Brewers' grains are supplied either wet or dry and are an excellent source of high quality bypass protein and digestible fibre.

17. Fermentation of cereal grains to make ethanol for industrial uses results in a protein-rich material (stillage) after the ethanol is distilled. The fermentation process predominantly consumes the starch in cereal grains, and the other nutrients, particularly protein, are concentrated (Wu 1989). The optimum recovery and use of stillage is important for the commercial success of the fermentation process. Stillage is usually centrifuged to yield a solid fraction (distillers' grains) and a soluble fraction (stillage solubles). Manufacturers typically dry the distillers' grains to yield dehydrated distillers' grains (DDG) and sell them as an ingredient for animal feed. The soluble fraction can be concentrated, blended with DDG, and co-dried yielding distillers' dried grains with solubles (DDGS). Wheat, however, is generally only an economical choice as a fermentation substrate if the DDG or DDGS can be sold as a human food ingredient rather than as a component of animal feed. Distillers' grains, including those from wheat, have been used as ingredients in baked goods and other foods to enhance protein and dietary fibre content.

E. Typical Criteria Used to Determine Wheat Quality

Grain Hardness

18. Bread wheat varieties can vary greatly in grain hardness and are usually classified into one of two categories – hard wheat or soft wheat. The terms "hard wheat" and "soft wheat", as used in this document, do not have the same meaning as described in EU regulations. In the EU, the term "hard wheat" is used exclusively for durum wheats, and the term "soft wheat" for *aestivum* or bread wheats, irrespective of the hardness of their grains. In this document, the terms "hard" and "soft" refer to the hardness of the grain.

19. The hardness of the grain is of particular relevance to the milling and baking industries. Hard grains exhibit more resistance to grinding than soft wheat grains and thus produce more damaged starch than soft wheat in the milling process (Belderok 2000). A certain degree of starch damage is desirable in bread baking as it contributes to the soft texture and pleasant mouthfeel of the crumb and also has a retarding effect on the bread going stale. Soft wheat flours have less damaged starch and are more suited to the production of biscuits, cakes, crackers, wafers, etc.

Moisture Content

20. Moisture content is considered one of the most important considerations in judging the quality of wheat because it is fundamental to the keeping and milling quality of the grain (Rasper and Walker 2000). The moisture content of commercial lots of wheat may vary between 8.0 and 18%, depending on the weather during harvest (Belderok 2000). Prior to milling, the moisture content of the grain is optimised by either the addition or removal of moisture. This ensures maximum milling efficiency and optimum performance in the final product (Bass 1988).

Protein Content

21. The protein content of wheat typically ranges between 10.0 and 16.0% (air dried matter), depending on the variety and the environmental conditions during the growth of the crop (see Tables 3 and 6). The hard wheats typically have higher protein contents than the soft wheats. Abundant rainfall during kernel development usually results in low protein content. Available soil nitrogen also has considerable influence on protein content. It is the protein content of kernel that generally dictates the end use of the flour produced.

Protein Quality

22. Varieties of wheat having the same total protein content can produce flours that behave quite differently in baking operations. In many instances these differences are attributed to qualitative differences in the gluten proteins. Gluten quality is largely a varietal characteristic, although high temperatures and low relative humidity during the period when the wheat is maturing in the field have a marked deleterious effect on the quality of the gluten.

Alpha-Amylase Activity

23. Wet weather after wheat has matured in the field but before harvest, may cause some of the kernels to sprout. These kernels are very high in α-amylase activity. Even if visible sprouting does not occur, the α-amylase level may be considerably elevated as a result of a wet harvest season. Although some α-amylase activity is optimal to sustain the production of sugars required for proper fermentation and subsequent gas production for bread making, excessively high levels of α-amylase can impair the quality of both the dough and the final baked product because of the rapid degradation of the starch molecules and subsequent reduction in viscosity of the dough (Rasper and Walker 2000).

Fat Acidity

24. Fat acidity refers to the breakdown of fats by lipases and the release of free fatty acids in the grain. Under most practical storage conditions, fat acidity in wheat increases after several years to levels considerably above those associated with freshly harvested sound wheat, even though the wheat shows no appreciable physical evidence of deterioration. Such wheat may still be useful for milling purposes but the keeping and baking quality of the flour may be adversely affected. Low temperature and moisture content during storage markedly reduce the rate of increase in fat acidity.

Crude Fibre and Ash

25. Both crude fibre and the ash content in wheat are related to the amount of bran in the wheat and hence have a rough inverse relationship to flour yield. Small or shrivelled kernels have more bran on a percentage basis and therefore more crude fibre and ash than large, plump kernels and consequently yield less flour. Wheat usually contains 2.0 – 2.7% crude fibre and 1.4 – 2.0% ash, both calculated to a 14% moisture basis.

F. Comparative analyses

26. This paper suggests parameters that wheat developers should measure when undertaking comparative analyses of new varieties of wheat. Data from the new variety should be compared to those obtained from the conventional counterpart and may also be compared to the literature values presented in this paper. Wheat composition is known to vary quite markedly from one area to another as well as from year to year within any given area (Matz 1991) therefore for effective comparison it is important that the new variety and its comparator (i.e., the control) are grown at the same site (preferably in adjacent plots) and at the same time. Also, given the variation that can occur in some constituents between different classes of wheat (e.g., in protein content between hard and soft wheats), it is important, when comparing results to the literature values for a particular constituent, the comparison is made to data derived from the same class of wheat.

SECTION II – NUTRIENTS IN WHEAT AND WHEAT PRODUCTS

27. Whole grain wheat is a major source of nutrients for humans as well as livestock. Although often seen mainly as a source of highly digestible carbohydrate, whole wheat is also recognised as a significant source of protein, the B vitamins, as well as a number of minerals, particularly iron, phosphorus, zinc, potassium and magnesium (Orth and Shellenberger 1988). Overall, wheat contributes slightly less than 20% of the world's total energy and protein (Betschart 1988), making it a significant staple food for the world population.

Table 2: Key wheat nutrients and their location in the kernel

Fraction	% Kernel (by weight)	Key Nutrients
Bran	8	Dietary fibre, protein, potassium, phosphorus, magnesium, iron and zinc
Aleurone layer	7	Protein, niacin, thiamine, folate, minerals – especially phosphorus (mainly as phytate), potassium, magnesium, iron and zinc
Endosperm	82	Starch, protein, minerals
Germ		
Embryo	1	Fats and lipids, protein and sugars
Scutellum	2	B vitamins (especially thiamine), phosphorus

(*Source*: Orth and Shellenberger 1988)

A. Whole Kernel and Fractions

28. Typical values for proximate composition of wheat are presented in Table 3 and the relative distribution of the major components in the various kernel fractions are presented in Table 4. Most of the mealy endosperm, used to derive the flour, consists of food reserves in the form of carbohydrate (mainly starch), whereas the bran contains high levels of fibre and comparatively more minerals and fat than the endosperm. The germ too contains comparatively high levels of fat and minerals and also contains significant amounts of fibre, carbohydrate and is also very rich in protein.

Table 3: Typical values for the proximate composition of whole wheat

Constituent	% air dried matter
Moisture	8.0 – 18.0
Protein	10.0 – 16.0
Ash	1.2 – 3.0
Carbohydrate	65.4 – 78.0
Fat	1.5 – 2.0
Energy	1377 - 1431 kJ/100 g
Crude fibre **Acid detergent fibre** **Neutral detergent fibre**	2.0 – 2.7 3.6 – 4.0 12.0 – 13.5

(*Source*: USDA 1999; Matz 1991; Belderok 2000; Ensminger *et al* 1990)

Table 4: Chemical composition (% dry matter) of whole wheat and its various fractions

	Kernel	Flour	Bran	Germ
Protein	16	13	16	22
Fat	2	1.5	5	7
Carbohydrate	68	82	16	40
Dietary fibre	11	1.5	53	25
Ash	1.8	0.5	7.2	4.5
Other	1.2	1.5	2.8	1.5
Total	100	100	100	100

(*Source*: Belderok 2000)

Carbohydrates

29. Carbohydrates constitute the bulk of the total dry matter of the wheat kernel, and are normally classified into three categories on the basis of their different monomeric and polymeric forms. The three categories are: the sugars, composed of the monosaccharides (glucose, fructose, galactose) and disaccharides (sucrose, maltose); the oligosaccharides (e.g., raffinose, stachyose); and the polysaccharides, composed of starch (amylose, amylopectin) and the non-starch polysaccharides (cellulose, pentosans, β-glucans) (FAO 1998).

30. The non-starch polysaccharides make up the bulk of what is termed *dietary fibre*, which also includes lignin (a non-carbohydrate component) plus resistant oligosaccharides and resistant starch (FAO 1998). The carbohydrate, and more particularly, the dietary fibre component of whole wheat confer significant health benefits to humans (Kritchevsky and Bonfield 1995).

31. The majority of the carbohydrate in wheat, of which most is found in the endosperm, is composed almost entirely of starch and serves as the energy source for the germ upon germination. As the most abundant carbohydrate component of wheat and wheat flour, wheat starch is also an important macronutrient for humans (Shelton and Lee 2000) as well as for other animals. Wheat starch is made up of two main fractions, amylose and amylopectin, which make up approximately 25 and 75% of the total starch mass, respectively. In addition to being an important energy source, starch also serves a number of important roles in bread making, such as providing a framework to which gluten can adhere, regulating the distribution of water in a loaf and filling up spaces that are created as the loaf changes shape during baking (Belderok 2000).

32. Other carbohydrate components, such as the sugars (glucose, fructose, galactose, sucrose, maltose) and the non-starch polysaccharides (cellulose, pentosans, and β-glucans) are present in lesser amounts and are located primarily in the bran and germ fractions. The fibre and carbohydrate components of the germ arise from contamination by the bran during milling.

33. Typical ranges for the various carbohydrate components of wheat, and its fractions, are given in Table 5. The carbohydrate content of wheat is subject to variation due to variety, environmental conditions, and also due to processing/milling conditions (Becker and Hanners 1991).

Table 5: Carbohydrate composition of wheat[1]

Component	Kernel (%)	Flour (%)	Bran (%)	Germ (%)
Total dietary fibre	11 – 14.6	2.3 – 5.6	43 – 53	13.2 – 15
Pentosans	1.4 – 6.7	1.1 – 1.4	21 – 43	6.6
Cellulose	2.0 – 2.7	0.3 – 0.6	7.2 – 8.0	2.7
Free sugars	2.1 – 2.6	1.2 – 2.1	7.6	16.0
Starch	59 – 72	65 – 74	14.1	28.7

[1] dry matter basis

(*Source*: Compiled from a number of sources, namely FAO 1998; Matz 1991; Becker and Hanners 1991; USDA 1999; Shelton and Lee 2000; Belderok 2000)

Proteins

34. In addition to its high energy content, wheat is also a good source of protein and contains considerably more protein on average than other cereals. The proteins of wheat are complex. They can be divided into two broad categories based on their biological functions: the biologically active enzymes (albumins and globulins) and the biologically inactive storage proteins (gliadins and glutenins) (Lookhart and Bean 2000). The gliadins and glutenins are referred to collectively as the gluten proteins, and are mainly located within the mealy endosperm of the grain, whereas the albumins and globulins are concentrated in the bran (the aleurone layer) and the germ. The gluten proteins play a key role in the formation of dough for bread making.

35. The protein content of wheat is affected by both the genetic makeup of the plant and by environmental conditions during growth of the plant, and development of the seed, therefore protein content can vary quite markedly, a typical range being from 10.0% to 16.0%. It is possible that, in the normal course of events, many samples will be found that fall outside this range because of unusual weather patterns, heavy fertiliser applications, disease or characteristics of a particular variety. For this reason it is important that an appropriate comparator is used for the comparative analysis. The typical protein contents of wheat, by class, are listed in Table 6.

Table 6: Protein content of wheat by class

Wheat class[1]	% dry matter
Hard red spring	13.6 – 15.8
Hard red winter	12.6 – 14.1
Soft red winter	10.4 – 13.0
Soft white winter	10.0 – 12.4
Soft white spring	13.5 – 14.2
Hard white winter	11.5 – 12.1
Hard white spring	12.3 – 13.4

[1] using the US classification

(*Source*: Davis *et al* 1981; Ensminger *et al* 1990; USDA 1999; NRC 1998)

36. Although wheat can be a significant source of protein, the nutritional quality of the protein for humans and other monogastric animals (for example, pigs and poultry) is limited by the low content of two essential amino acids, lysine and threonine (Matz 1991, Shewry *et al* 1994). Of these, lysine is the more limiting. Because of this, it is necessary to mix wheat with more lysine-rich proteins to provide a balanced diet or to provide lysine as a supplement in animal feeds. The low levels of lysine in the kernel result from the low proportions of lysine in the gluten proteins, which are located mainly in the endosperm, whereas the lysine-rich albumins and globulins are located mainly in the bran and the germ (Lookhart and Bean 2000). Wheat germ is the grain fraction that contains the most lysine (Matz 1991). The amino acid content of wheat and its fractions are listed in Table 7.

Table 7: Typical amino acid composition of wheats (% total protein)

Amino acid	**Kernel**	**Flour**	**Bran**	**Germ**
Tryptophan	1.0 – 2.1	0.7 – 1.0	1.6 – 1.8	1.0 – 1.3
Threonine	2.4 – 3.2	2.2 – 3.0	2.6 – 3.5	3.4 – 4.2
Isoleucine	3.0 – 4.3	3.4 – 4.1	3.1 – 3.8	3.5 – 3.9
Leucine	5.0 – 7.3	6.5 – 7.2	5.5 – 6.8	5.7 – 6.8
Lysine	2.2 – 3.0	1.8 – 2.4	3.5 – 4.5	5.3 – 6.3
Methionine	1.3 – 1.7	0.9 – 1.5	1.1 – 1.6	1.7 – 2.0
Cystine	1.7 – 2.7	1.6 – 2.6	1.5 – 2.4	1.0 – 2.0
Phenylalanine	3.5 – 5.4	4.5 – 4.9	3.2 – 4.0	3.4 – 4.0
Tyrosine	1.8 – 3.7	1.8 – 3.2	2.1 – 2.8	2.8 – 3.0
Valine	4.4 – 4.8	3.7 – 4.5	4.0 – 5.1	4.7 – 5.2
Arginine	4.0 – 5.7	3.1 – 3.8	5.5 – 7.0	6.9 – 8.1
Histidine	2.0 – 2.8	1.9 – 2.6	2.1 – 2.8	2.3 – 2.8
Alanine	3.4 – 3.7	2.8 – 3.0	4.6 – 4.9	5.2 – 6.4
Aspartic acid	4.8 – 5.6	3.7 – 4.2	6.6 – 7.3	7.5 – 8.9
Glutamic acid	29.9 – 34.8	34.5 – 36.9	16.2 – 20.8	14.0 – 17.3
Glycine	3.8 – 6.1	3.2 – 3.5	5.0 – 7.1	5.2 – 6.2
Proline	9.8 – 11.6	11.4 – 11.7	5.7 – 6.9	5.0 – 5.3
Serine	4.3 – 5.7	3.7 – 4.8	4.4 – 4.6	4.5 – 4.8

(*Source*: Pomeranz 1988; Ensminger *et al* 1990; USDA 1999; Lookhart and Bean 2000; Posner 2000)

Vitamins

37. In the wheat kernel, the vitamin content can vary from one part of the grain to another (see Table 2) with vitamins being found in high concentrations in the germ and bran. The removal of these kernel structures during the milling process can result in significant loss of certain vitamins. The vitamin content of wheat is also known to be highly variable (Pomeranz 1988). Significant differences in vitamin content may occur due to variety, crop year, crop site, fertilisation practices, soil type, wheat class, and the analytical techniques used.

38. Wheat has relatively low levels of lipids and hence tends to only contain low amounts of the fat-soluble vitamins – provitamin A, and vitamins D, E and K. The exception to this is the germ fraction, which contains relatively high levels of lipids and hence, the tocopherols, which are responsible for the vitamin E activity of plant tissues, are most abundant in this fraction. Wheat germ oil is considered a particularly rich source of vitamin E. Wheat has only four major tocol derivatives, namely α-tocopherol (α-T), α-tocotrienol (α-T-3), β-tocopherol (β-T) and β-tocotrienol (β-T-3), with α-T being the major form in wheat (Morrison 1981). The γ- and δ-tocopherols and tocotrienols either are absent or are only present in trace amounts. Among cereal grains, the wheat tocopherols are considered to have particularly good vitamin E activity and antioxidant properties (Morrison 1981).

Table 8: Tocol derivative content (mg/100g) of whole wheat and its fractions

Grain Fraction	α-T	α-T-3	β-T	β-T-3	Total
Whole grain	0.9-1.8	0.2-0.7	0.4-0.9	1.9-3.6	4.9-5.8
Germ	22.1-25.6	<0.2-0.3	8.6-11.4	<0.2-1.0	N/A
Bran	1.6-3.3	1.1-1.5	0.8-1.3	2.9-5.6	N/A
Endosperm	0.007	0.045	0.01	1.4	1.4

N/A: not available
(*Source*: Chung and Ohm 2000)

39. Compared to maize, the carotenoids are considered to be very minor constituents of wheat. Their very low levels mean that wheat is not a significant source of vitamin A precursors and thus wheat carotenoids are not considered to have any nutritional importance (Bock 2000). The colour due to carotenoids, however, is an important factor in the use of cereal grains in food production, particularly in durum wheat used to make pasta. The major carotenoids of bread wheat are carotene, xanthophyll and xanthophyll ester. The carotenoids are not homogenously distributed in the wheat kernel. Bran contains 0.9 – 0.95 mg/kg; germ contains 7.2 – 11.0 mg/kg; and endosperm contains 1.6 – 2.2 mg/kg (Chung and Ohm 2000). Carotenoid composition also differs among wheat classes and wheat fractions within a given class of wheat.

40. Whole wheat is considered to be a particularly good source of the B vitamins, especially thiamine, riboflavin, niacin, and pyridoxine (vitamin B_6), and is also a moderate source of folic acid. These vitamins are concentrated in the bran (aleurone layer) and germ. Typical ranges in vitamin content are shown in Tables 9 and 10.

Table 9: Vitamin content (mg/100g, dry weight basis) of whole wheat

Vitamin	Range
Thiamine	0.13 – 0.99
Riboflavin	0.06 – 0.31
Niacin	2.20– 11.10
Pyridoxine	0.09 – 0.79
Folic acid	0.02 – 0.09

(*Source*: Davis *et al* 1984a)

Table 10: Vitamin content (mg/100g, dry weight basis) of whole wheat by class[1]

Vitamin	HRW	HRS	SRW	HWW	SWS	SWW
Thiamine	0.334 – 0.57	0.416 – 0.50	0.411 – 0.51	N/A	0.46 – 0.50	0.411 – 0.46
Riboflavin	0.11 – 0.14			N/A	0.10 – 0.15	
Niacin	4.95 – 7.4	4.97 – 6.25	4.84 – 6.70	4.33 – 4.90	4.68 – 6.00	5.19 – 5.59
Pyridoxine	0.092 – 0.53	0.202- 0.53	0.169 – 0.38	N/A	N/A	N/A

[1] according to the US classification

HRW: hard red winter; HRS: hard red spring; SRW: soft red winter; HWW: hard white winter; SWS: soft white spring; SWW: soft white winter; N/A: not available (*Source*: Davis *et al* 1984a)

Minerals

41. The average mineral content of a given wheat grain varies significantly from one part of the world to another. This appears to be a function of a number of factors, including the wheat variety, the growing and soil conditions, and fertiliser application (Davis *et al* 1984b, Bock 2000). The mineral

composition of wheat has more to do with environmental conditions, rather than varietal characteristics. Major constituents of the mineral fraction of wheat are magnesium, phosphorus and potassium. There are also significant amounts of copper, iron, manganese and zinc present (Davis *et al* 1984b). As with the vitamins, minerals are especially concentrated in the bran (aleurone layer), therefore the milling process can also result in significant losses of minerals, especially copper, iron, manganese and zinc.

42. In wheat, phosphorus is mostly present in the form of calcium, potassium or magnesium phytate (Hazell 1985), primarily in the bran fraction. Whole wheat, wheat germ and wheat bran are classified as high sources of phosphorus (Bock 2000), although most of this is biologically unavailable to monogastric animals, including humans. Whole cereal grains and particularly wheat are the main sources of magnesium for humans. Magnesium is located primarily in the bran fraction and also binds with phytic acid. Whole wheat is considered to be a moderately good source of magnesium, with wheat bran and wheat germ considered to be high sources (Bock 2000). The iron in wheat is located in the outer endosperm and bran. Both wheat germ and wheat bran are considered to be good sources of dietary iron (Bock 2000). Wheat germ and bran are also excellent sources of dietary zinc and are also the only cereal products that serve as good sources of copper (Bock 2000).

Lipids

43. Lipids are relatively minor constituents of the kernel, however they are important nutritionally as well as for grain storage and processing. Measured lipid content and composition depend largely on extraction and purification procedures and to a lesser extent on the samples, therefore care should be taken when comparing lipid content or composition data reported in the literature. The lipid content of wheat typically ranges from 1.5 to 2.0% but is not dispersed evenly throughout the grain, with between 34 and 42% of the lipid being in the germ fraction (Zeringue and Feuge 1980).

44. The majority of the lipids in wheat are acyl lipids containing the fatty acids commonly found in higher plants, that is, palmitic (16:0), stearic (18:0), oleic (18:1, *n-9*), linoleic (18:2, *n-6*) and linolenic (18:3, *n-3*) acids. The typical fatty acid composition of whole wheat is presented in Table 11.

Table 11: Typical fatty acid composition (% total fatty acids) of wheat

Fatty acid	Kernel	Germ
Palmitic acid	11 - 32	18 - 19
Stearic acid	0 – 4.6	N/A
Oleic acid	11 - 29	8 - 17
Linoleic acid	44 - 74	57 - 62
Linolenic acid	0.7 – 4.4	7 - 11

N/A: not available

(*Source*: Davis *et al* 1980; Barnes 1982, cited in Pomeranz 1988)

45. The main nonsaponifiable components of lipids in wheat are the tocol derivatives and carotenoids (discussed above), plus the sterols. Of the sterols, β-sitosterol is the primary sterol in all cereal grains and comprises 41 – 53% of the total sterols found in wheat. Campesterol is the next most abundant sterol found in wheat. The total sterol content has been estimated as 0.5% of the germ (Pomeranz 1988).

Other components

46. Wheat also contains a number of other constituents, some of which, at higher intakes, are suggested to be implicated in protection against disease (Thompson 1994, Slavin *et al* 1997). These include phenolic acids, lignans, and the flavonoids.

47. The most abundant phenolic acid is ferulic acid, followed by vanillic, *p*-coumaric, protocatechuic, syringic, *p*-hydroxybenzoic, caffeic, and genitisic acids. Ferulic acid is ester-linked to specific polysaccharides (the arabinoxylans), which form 65% of the aleurone cell walls. Bacterial enzymes in the human colon slowly and partially degrade the aleurone cell walls. This degradation results in the release of feruloylated oligosaccharides, which can then be further degraded to release ferulic acid. Ferulic acid is a good antioxidant (Rice-Evans *et al* 1997).

48. The flavonoids are a large group of phenolic compounds that occur widely in plants. Many of them have good antioxidant properties (Ferguson and Harris 1999). The highest concentration of flavonoids in whole wheat is in the germ followed by the bran. Flavonoids have structures based on a C15 nucleus and are usually grouped into classes (e.g., flavones). The flavone tricin, as well as two glycosides of the flavone apigenin have been identified from wheat bran. Wheat bran also contains small amounts of the flavonol catechin and proanthocyanidin (also known as condensed tannins), which are oligomers or polymers based on flavonol units.

49. The lignans are phenolic dimers, and are predominantly present in the bran (Nilsson *et al* 1997). They are converted by fermentation in the large intestine to mammalian lignans.

B. Whole plant

50. In addition to the production of grains, which contain large quantities of carbohydrates, the entire wheat plant can be used for forage – pasture, hay, or silage – for grazing animals. In addition, by-products of the harvested grains, such as chaff, stover and straw, can be used as low-quality forages for ruminant animals. The typical constituents measured in wheat forage are shown in Table 12.

Table 12: Typical constituents measured in wheat forage

Analysis	**Forage type**			
	Hay, sun-cured	**Chaff**	**Straw**	**Immature, fresh**
Proximate Analysis:				
Dry matter	89	93	90	22
Ash	7.0	15.6	6.9	3.0
Neutral detergent fibre	60.5	N/A	70.3	10.2
Acid detergent fibre	36.5	N/A	47.7	6.3
Crude fat	2.0	1.9	1.8	1.0
N-free extract	46.4	39.5	40.4	8.3
Crude protein	7.7	5.4	3.2	6.1
Minerals:				
Calcium	0.13	0.19	0.16	0.09
Phosphorus	0.18	0.08	0.05	0.09

N/A: not available
(*Source*: Ensminger *et al* 1990)

C. Other wheat products

Dehydrated Distillers Grains

51. Wheat DDGS and products prepared by fractionation of DDGS have a very high protein content (29 – 59%) as well as dietary fibre content (40 – 55%). Wheat DDGS also provide higher levels of calcium, iron and zinc than whole wheat. The level of thiamine, however, is significantly lower in DDGS (0.09 – 0.19 mg/100 g dry weight) than in wheat flour (0.162 – 0.168 mg/100 g dry weight) or whole grain (see Table 9 and 10) but the level of riboflavin is comparable (0.17 – 0.50 mg/100 g dry weight).

SECTION III – ANTI-NUTRIENTS, ALLERGENS AND OTHER COMPOUNDS IN WHEAT AND WHEAT PRODUCTS

52. Compared to the legumes, the content of common anti-nutrients in cereals, including wheat, is considered to be quite low (Klopfenstein 2000).

A. Anti-nutrients

Protease and Amylase Inhibitors

53. Protease inhibitors, especially trypsin inhibitors, may decrease the digestibility and biological value of ingested protein and retard growth when sufficient amounts are present in the diet and amylase inhibitors may affect the digestibility of starch. Both protease and amylase inhibitors have been identified in wheat, however they do not appear to be responsible for any serious anti-nutritional activity in humans (Klopfenstein 2000), probably because both inhibitor types tend to be heat labile.

54. The type of amylase inhibitor found in wheat is fairly common and although found to be present at quite high concentrations is relatively heat labile (Wiseman *et al* 1998). The inhibitor is mainly associated with the starch granules in the endosperm with very little present within the bran portion. Wheat amylase inhibitor is found to be active against chicken pancreatic amylases, although in practice it is unlikely to have much nutritional significance in chickens since it is largely inactivated by pepsin in the gizzard (Macri *et al* 1977).

Lectins

55. Lectins, sometimes called phytohemagglutinins, are glycoproteins that bind to certain carbohydrate groups on cell surfaces, such as intestinal epithelial cells, where they cause lesions and severe disruption and abnormal development of the microvilli (Liener 1989). One of the major consequences of the lectin damage to the intestinal mucosa appears to be serious impairment in the absorption of nutrients across the intestinal wall.

56. Although more commonly associated with legumes, cereal grains, including wheat are also known to contain lectins, although their possible physiological significance is unknown because of the absence of suitable studies (Liener 1989). As lectins are usually inactivated by heat treatment, they are really only of interest when raw or inadequately cooked food or feed is consumed. Therefore, in the case of wheat they are more likely to be an animal feed concern. Although lectins have been detected in wheat, as well as wheat germ, virtually no evidence exists of any significant anti-nutritional effect of these lectins (Klopfenstein 2000).

Phytic acid

57. Phytic acid (myo-inositol hexaphosphate) chelates minerals such as iron, zinc, phosphate, calcium, potassium and magnesium. The bioavailability of trace elements such as zinc and iron can thus be reduced by the presence of phytic acid in monogastric animals, although in humans, phytic acid does not seem to have a major affect on potassium, phosphorus or magnesium assimilation. Ruminants, on the other hand, are more readily able to utilise phytate-complexed minerals such as phosphorus because they have abundant amounts of microbial phytase, which degrades phytate, in the rumen. The typical levels of phytate in various wheat fractions are given in Table 13.

Table 13: Phytate content of wheat

Food	**mg Phytate/100 g edible portion**
Wheat flour, all purpose	282
Wheat flour, whole wheat	845
Wheat bran, crude	3011
Wheat germ	4071

(*Source*: adapted from Harland 1993)

B. Wheat allergens

58. Wheat is one of the most common allergenic foods associated with IgE-mediated reactions in the world (FAO 1995) but has only rarely been reported to cause anaphylaxis (Bousquet *et al* 1998, Takizawa *et al* 2001). Wheat is most commonly associated with the (IgE-mediated) conditions known as baker's asthma, resulting from the inhalation of wheat flour, and atopic dermatitis. The ingestion of wheat flour has also produced anaphylaxis in rare instances in children.

59. A diversity of allergens appear to be implicated in each of these conditions, with some in common between conditions, although thus far the specific allergens involved have not been identified. In baker's asthma, components of both the water/salt-soluble fraction (globulins and albumin) and the water/salt-insoluble fraction (gliadins and glutenins) have been reported to be allergens (Sutton *et al* 1984, Franken *et al* 1994, Sandiford *et al* 1997). In cases of food-dependent, exercise-induced anaphylaxis, gliadin has been reported to be an allergen prominently involved (Palosuo *et al* 1999). In cases of non-exercise-induced anaphylaxis in young children resulting from the ingestion of wheat flour, two or more protein components of the wheat proteins appear to be implicated and some of the proteins characterised are in common with those implicated in cases of atopic dermatitis (Takizawa *et al* 2001).

60. Wheat, along with other gluten-containing cereals such as rye and barley, is also associated with a condition known as gluten-sensitive enteropathy (also called coeliac disease), which affects genetically predisposed individuals (FAO 2001). The response is triggered by gliadin (Howdle *et al* 1984).

C. Other compounds

DIBOA and DIMBOA

61. Hydroxamic acids and benzoxazinoids belong to a group of metabolites commonly found in roots and leaves, but not in seeds, of cereal plants. In young plantlets (seedlings) of wheat, DIBOA (2,4-dihydroxy-2*H*-1,4-benzoxazin-3(4*H*)-one) and DIMBOA (2,4-dihydroxy-7-methoxy-2*H*-1,4-benzoxazin-

3(4*H*)-one) are prominent representatives of these metabolites, both in glycosylated and non glycosylated form (Nagakawa *et al* 1995). High tissue levels of DIBOA and DIMBOA are associated with insect resistance, for example aphid resistance, of wheat obtained through conventional breeding.

62. After reaching their maximum during the first days of plant development, levels of DIBOA and DIMBOA decrease in the time thereafter, and are relatively low in flag leaves and ears at late growth stages (Copaja *et al* 1999, Nicol and Wratten 1997). In addition, levels vary between varieties. For example, young plantlets of screened wheat varieties contained 0 - 1.1 mmol (kg fw)$^{-1}$ DIBOA and 1.4 - 10.9 mmol (kg fw)$^{-1}$ DIMBOA (Copaja *et al* 1991).

63. The mechanism of DIBOA’s and DIMBOA’s toxicity to insects has not been elucidated yet. In addition, data on the possible toxic and physiological effects of DIBOA, DIMBOA, and related compounds on humans and domestic animals are scarce. One report, for example, describes the *in vitro* mutagenicity of DIBOA and DIMBOA in the Ames test (Hashimoto *et al* 1979). In addition, a number of reports document hormonal effects of MBOA, a metabolite of DIMBOA, in wild rodents (Korn 1988). Data on hormonal effects of MBOA in domestic animals are, however, fragmentary.

SECTION IV – FOOD USE

A. Identification of the Key Wheat Products Consumed by Humans

64. Nearly 600 million tonnes of wheat are produced annually worldwide (FAO 2002), with the majority of this destined for human consumption. Wheat and wheat foods are a major source of nutrients for people in many regions of the world. Overall, cereal grains contribute 50 and 45% of the world's dietary calories and protein, respectively with wheat providing slightly less than 20% of total calories and protein (Betschart 1988). The importance of wheat as a human food is primarily due to the fact that the wheat kernel can be ground into flour, which forms the basic ingredient of bread and other products, such as breakfast cereals, biscuits, cakes, pastry, and noodles. Other products of the dry milling process – the bran and the germ – are also highly valued as food: both are good sources of vitamins and minerals and the bran is also a good source of dietary fibre, and the germ is rich in vitamin E (measured as α-tocopherol).

B. Identification of Key Constituents and Suggested Analysis for Food Use

65. The suggested key constituents to be analysed for human food use are shown in Table 14. As all the food products are derived from the whole grain it is considered sufficient, in most circumstances, to analyse key constituents for the kernel only and it will not be necessary to separately analyse key constituents for the derived fractions, that is, the flour, bran or germ. Depending on the nature and purpose of the specific modification, however, additional analyses of the various derived fractions may also be useful.

Table 14: Suggested constituents to be analysed in wheat for human food use

Constituents	Kernel	Flour	Bran	Germ
Proximate	√	√	√	√
Amino acids	√			
Fatty acids				√
α-Tocopherol	√			√
B Vitamins	√	√	√	
Phytate	√		√	

SECTION V – FEED USE

66. Traditionally, wheat is considered a good animal feed, with approximately 16% of the world wheat production going into animal feeds. Wheat is said to compare favourably with corn in feed value and is regarded as superior to barley (Matz 1991). Although corn has the higher energy value, wheat has the highest amount of crude protein (Ensminger *et al* 1990).

A. Identification of the Key Wheat Products Consumed by Animals

67. The key wheat products in animal feeding can be divided into three categories: (i) whole and minimally processed grain; (ii) processing by-products; and (iii) forages derived from the whole plant.

Whole and minimally processed grain

68. Whole and minimally processed grain is fed to animals primarily for its high energy content and also because it is a valuable source of protein, vitamins, and minerals. The grain also contains relatively low levels of fibre and thus is a highly digestible feed for both non-ruminants and ruminants. The grain however is not used very extensively in animal rations because of its high cost, however, in years in which harvests are adversely affected by rain and significant quantities of the grain are made unsuitable for milling because of sprouting, significant quantities of grain may be used for feed. The use of wheat for animal feeding varies from country to country. For example, most US wheat is used for human food whereas in Europe, where there is often a surplus of wheat, large quantities are fed to livestock (Ensminger *et al* 1990). Most of the European feed wheat is thus of the hard or medium-hard type, whereas, in the US, most wheat for animal feed is of the soft type, which is not as valuable for milling (Matz 1991).

69. Due to the low crude fibre content and high digestibility, wheat is a valuable starch source for various animals. Limitations on the amount of grain that can be included in the diet are generally not necessary, although digestive upsets in some young animals are known. For this reason, it is usually recommended that the proportion of wheat grain in the concentrate mix not exceed 50% in diets for piglets and 20% for chickens and broilers. The wheat grain is usually cracked, crushed or coarsely ground to improve palatability and digestibility. Heat processing (hot extrusion, steam flaking and popping) does not appear to improve the palatability or performance of wheat used as feed over minimally processed wheat (Matz 1991).

Processing by-products

70. The amount of milling by-products used in animal feeds is almost entirely a function of the demand for flour (Matz 1991). In the US, wheat is cultivated primarily as a food grain for human consumption. As a result most of the wheat fed to livestock is in the form of mill by-products.

71. By-products of the dry milling of wheat have long been employed as ingredients of animal feeds. Generally millers remove about 80% of the kernel for wheat flour and the other 20% goes into the

production of livestock feeds, generally described as wheat middlings, wheat bran, wheat shorts, wheat red dog, wheat screenings, wheat germ meal and wheat germ oil. With the exception of wheat germ meal and oil, such individual by-products have largely lost their identity in the milling industry. Many flourmills combine all by-product streams with the screenings, merchandising a single product (generally termed "millfeed") to the feed industry, with individual by-products generally not being available (Dale 1996).

72. Wheat millfeeds are suitable for many types of livestock rations. Millfeeds are usually combined with other cereal grains and various supplements when fed to cattle and are often used in swine feeds but are rarely fed to sheep, although wheat bran is a favoured supplement for use in gestating sheep rations. Most horse rations contain an average of about 10% wheat bran (Matz 1991).

73. By-products from fermentation and brewing processes, such as DDGS and brewers grains, are also important constituents of animal feeds. They serve as cheap energy sources and are particularly valuable for their protein content, as well as their vitamins and mineral content.

Whole plant

74. In addition to the production of grains, the entire wheat plant can be used for forage – pasture, hay, or silage, which are all important categories in animal feeding (Matz 1991). Winter wheat is an excellent source of pasture in the autumn and early spring, particularly for cattle. The by-products of the harvested grain, such as chaff, stover and straw can also be used as low-quality forages for ruminant animals (Ensminger *et al* 1990). They are generally high in fibre and low in protein and can be used as filler and also to provide some nutrients for cattle.

B. Identification of Key Constituents and Suggested Analysis for Feed Use

75. The suggested nutritional and compositional parameters to be analysed for animal feed use are shown in Table 15. Analysis of processing by-products should not be necessary as all the animal feed products are derived from either the whole grain or the whole plant.

Table 15: Suggested constituents to be analysed in wheat for feed use

Parameter	**Kernel**	**Whole plant**
Proximate	√	√
Amino acids	√	
Fatty acids	√	
Phytate	√	

76. The key analysis for animal feeds is the proximate analysis. Feeds are typically evaluated in terms of six components – moisture (dry matter), ash (mineral matter), crude protein (N X 6.25), ether extract (fat, organic acids, pigments, alcohols and fat soluble vitamins), crude fibre (cellulose, hemicellulose and lignin) and carbohydrate (starch, sugars, some cellulose, hemicellulose and lignin). For proximate analysis of animal feeds, acid-detergent fibre (ADF) and neutral-detergent fibre (NDF) should be substituted for crude fibre analysis. These give an indication of the digestibility of the feed and are particularly important for forage analysis.

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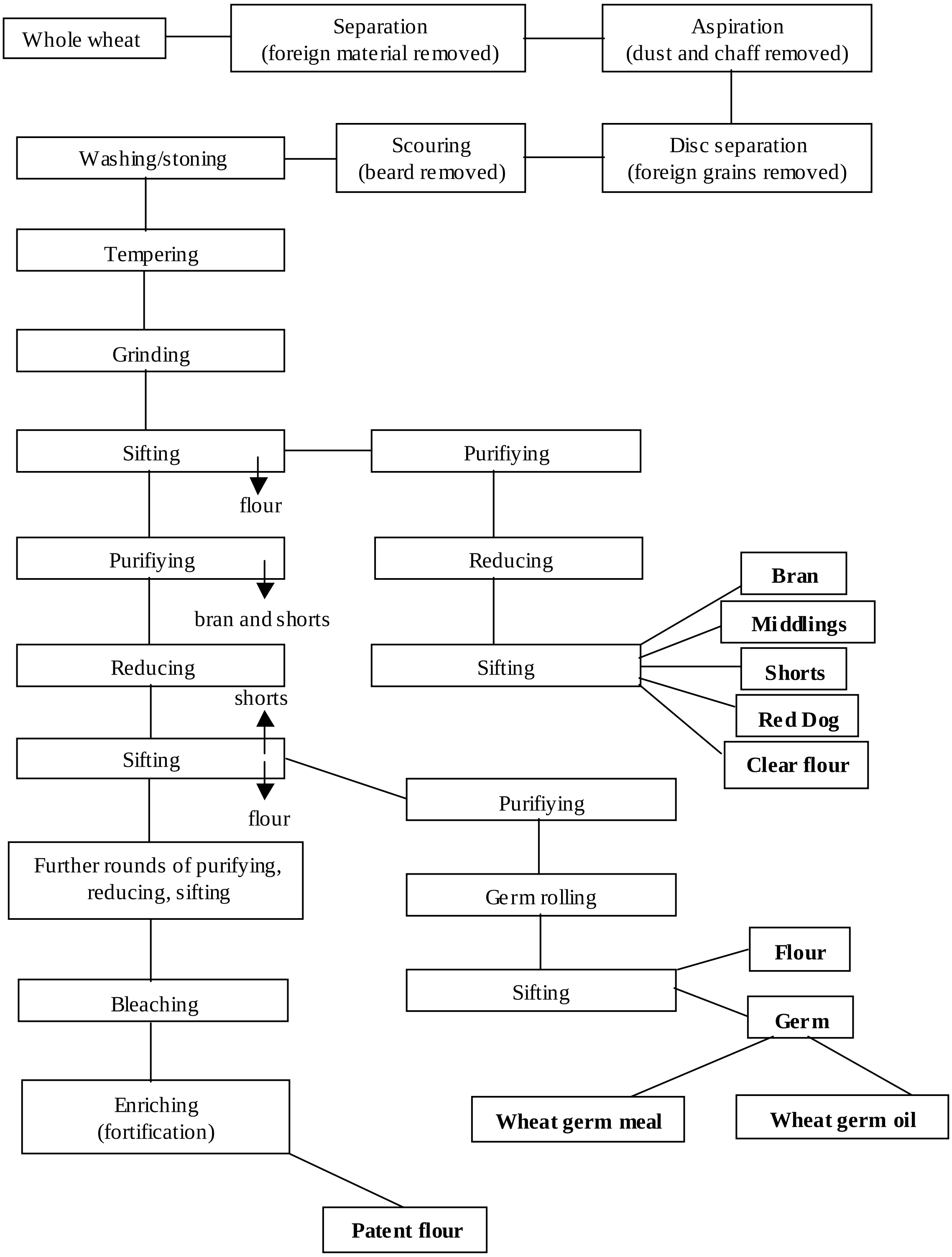
Fig. 1. Dry Milling of Wheat (adapted from Matz 1991)



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