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CONSENSUS DOCUMENT ON COMPOSITIONAL CONSIDERATIONS FOR NEW VARIETIES OF BARLEY (HORDEUM VULGARE l.): KEY FOOD AND FEED NUTRIENTS AND ANTI-NUTRIENTS

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Series on the Safety of Novel Foods and Feeds

No. 12

CONSENSUS DOCUMENT ON COMPOSITIONAL CONSIDERATIONS FOR NEW VARIETIES OF BARLEY (*HORDEUM VULGARE* L.): KEY FOOD AND FEED NUTRIENTS AND ANTI-NUTRIENTS

Environment Directorate

Organisation for Economic Co-operation and Development

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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 barley by identifying the key food and feed nutrients and anti-nutrients. A general description of these components is provided. As well, there is background material on the production, processing and uses of barley and considerations to be taken when assessing new barley varieties.

Finland, Germany and the United States 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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

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 phenotypic characteristics and 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 COMPARATIVE APPROACH AS PART OF A SAFETY ASSESSMENT

In 1990, a joint consultation of the Food and Agriculture Organisation of the United Nations (FAO) and the World Health Organisation (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) 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 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, 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 Barley

Barley (*Hordeum vulgare* L.) is grown as a commercial crop in some one hundred countries world-wide and is one of the most important cereal crops in the world. Barley assumes the fourth position in total cereal production in the world after wheat, rice, and maize, each of which covers nearly 30% of the world's total cereal production (FAOSTAT data, 2004). The Russian Federation, Canada, Germany, Ukraine and France are the major barley producers accounting for nearly half of the total world production. Data on the total production and major producers in 2001 are shown in Table 1.

Table 1.Barley production in 2001

Country/ Region	Area harvested (million ha)	Grain yield (tonnes/ha)	Total production (million tonnes)
Australia	3.4	1.9	7.5
Canada	4.4	2.6	11.4
France	1.7	5.7	9.8
Germany	2.1	6.4	13.6
Russian Federation	7.7	2.5	19.5
Spain	3.0	2.1	6.2
Turkey	3.6	1.9	6.6
Ukraine	3.9	2.6	10.2
United Kingdom	1.2	5.4	6.7
United States	1.7	3.1	5.4
World Total	**54.3**	**2.6**	**141.2**

Source: FAOSTAT data, 2004

The major barley grain importers in 2000 were Saudi Arabia, China, Japan and Belgium. Table 2 presents the import situation in 2000.

Table 2.Import of barley grain in 2000

Region	Million tonnes	Share in total (%)
Algeria	0.6	2.6
Belgium	1.2	5.5
China	2.1	9.5
Germany	0.7	2.9
Iran	1.0	4.7
Italy	0.7	3.0
Japan	1.7	7.4
Morocco	0.9	3.9
The Netherlands	0.6	2.5
Saudi Arabia	5.3	24.0
Tunisia	0.4	1.8
USA	0.6	2.6
Others	6.6	29.6
World total	**22.4**	**100.0**

Source: FAOSTAT data, 2004

B. Classification of Barley

Barley is one of the most ancient crops cultivated already some 10 000 years ago. Barley cultivated for food and feed belongs to the species *Hordeum vulgare* L. (Harlan, 1995). Although the barley crop is distributed throughout the world, its supposed progenitor, *Hordeum vulgare* L. ssp. *spontaneum* C. Koch, occurred in a more restricted area, namely the Middle East and adjacent regions of North Africa (Ellis, 2002). After domestication, unrecorded migration and trade would have rapidly distributed the barley crop outside the region of its origin. The result is the development of landraces adapted to northern and western European environments and later to North American, Australian, and Southern African environments (Ellis, 2002).

Barley is well adapted to a wide range of environments. It is grown in different latitudes from the equator up to the 65th latitude in the north and to the 50th latitude in the south as well as from sea level up to mountain slopes. Consequently, the list of agronomic criteria used in breeding consists of at least increased and stable yield, early flowering and harvest, winter hardiness, resistance to extremes of temperature, edaphic factors and water stress, resistance to drought and soil acidity, salt tolerance, resistance to diseases and insect pests, and lodging. Quality criteria for breeding are determined according to the respective uses (processing characteristics and nutritional value) of barley.

Extensive cultivation, intensive breeding and selection have resulted in thousands of commercial varieties of barley. For commercial purposes, barley varieties are classified into broad classes that are used as a basis for world trade. The major factors used to distinguish barley varieties are feed or malting barley, winter or spring growth habit, 6-, 4- or 2-row varieties, covered or naked/hulled barley, and starch amylose/amylopectin ratio.

C. Uses of Barley

It is estimated that about 85% of the world's barley production is destined for feeding animals, while the rest is used for malt production, seed production and food consumption but also for production of starch either for food use or for the chemical industry (Fischbeck, 2002).

Barley grain based feeds are used on pig and cattle farms. Barley is a valuable grain for finishing beef cattle in the United States and is also used in swine diets particularly in geographic regions where maize cannot be economically produced. In these climates, it competes with wheat as a feed, though it is considered to have a poorer nutritive value because of its higher fibre content.

Although malt from barley can be used for a number of purposes the brewing industry utilizes most of the barley malt produced (Fischbeck, 2002). In 2000 the main barley malt exporters were France, Belgium, Germany, Canada and Australia whereas the importers were Japan, Brazil and the Russian Federation (FAOSTAT data, 2004). The United States, China and Germany are the major beer producing countries. The United States and China together produced in 2001 more than one third of the world total of 132.2 million tonnes of beer (FAOSTAT data, 2004).

In some countries (see Table 3), such as Morocco, India, China and Ethiopia, barley is used as an important food crop in daily diets (Bekele *et al*., 2001; Ceccarelli *et al*., 1999). Furthermore, some non-alcoholic drinks, based on barley and malt, are consumed and for instance 'barley tea' has a longer history of use than green tea in Japan. For production of barley tea, six-rowed barley in Canada, two-rowed barley in Australia, and the others are imported.

Table 3.Use of barley for food consumption in 2002

Country/Region	Consumption (thousand tonnes)	Share in total food consumption (%)
Algeria	480	6.7
China	661	9.2
Ethiopia	887	12.3
Germany	170	2.4
India	1108	15.4
Republic of Korea	220	3.1
Morocco	1071	14.9
Poland	205	2.8
Ukraine	161	2.8
USA	149	2.0
World Total	**7207**	**100.0**

Source: FAOSTAT data, 2004

D. Processing of Barley

The processing of barley for food can be divided into the following categories: (i) fractionation to produce pure barley starch, and fibre; (ii) germination to produce barley malt; (iii) milling and flaking; and (iv) production of non-alcoholic beverages. Barley starch is used in the food industry as a thickener and after hydrolysis as a sweetener and in the paper industry as

coating material. The insoluble residue from the ethanol production, the distillers' grains as well as the fibre fraction, are used for feed. Barley malt is mainly used for beer production while smaller amounts are used by the whisky distilling industry and by bakeries. Both brewers' and distillers' grains are used as animal feeds as well.

Fractionation process for starch and fibre (Appendix 1)

When producing starch, barley grains are first milled in two steps. After removing the hull fraction, the kernels are soaked with enzymes in water. After the separation of fibres and protein the barley starch is purified in hydrocyclones and dried resulting in a pure barley starch product.

Part of this starch and fermentable sugars are also used as raw materials in alcohol production. After continuous mashing with enzymes and fermentation with yeast, the fermented mash is distilled in a number of columns. The resulting products are both high quality grain alcohol as well as industrial ethanol. The by-products such as carbon dioxide may be sold to industry and concentrated stillage solubles is sold to farmers as feeding stuffs. Hulls are usually burned in the processor's power plant.

Malting and fermentation (Appendix 2)

An overview of the typical processing steps from barley to beer is shown in Appendix 2. The objective of malting is to promote the production of endogenous enzymes capable of hydrolysing the grain macromolecules to soluble compounds. The hydrolysis starts already during malting and proceeds further during wort production in the brewery or distillery.

Malting process

The malting process consists of three stages: steeping, germination and kilning. During steeping the barley is washed with water and the moisture content is increased, normally to 43-48%. During germination the acrospire grows under the hulls and rootlets break through the end of the grain. Rootlets, rich in protein, are mechanically separated from the kilned malt.

Beer and whisky production

Beer production consists of three main stages: wort production; fermentation; and downstream processing. To receive wort that contains fermentable sugars and other nutrients for yeast fermentation the grain components are solubilised and hydrolysed by the enzymes produced during germination. After mashing insoluble particles are separated and the mash cake is washed with hot water. The sweet wort is sterilised by boiling before the addition of yeast.

Malt whisky production is analogous to that of beer. The fermented mixture is distilled and the distillate is stored for several years. In grain whisky production, high enzyme malt is used mainly as enzyme source and the main raw material is cooked maize and un-malted wheat or barley. The whole mash is cooled and fermented which allows the continuous the action of malt enzymes during fermentation. After fermentation the entire mixture is distilled and the residue, distillers' grains, is dried and used as feeding stuff.

Malt syrups and extracts

Sweet wort can also be concentrated. The resulting malt syrup is used for baking, making candy and other food purposes. Malt extracts are prepared by vacuum concentration of the wort to obtain extracts and syrups of different colours, solid contents and enzyme activity. Depending on the drying temperatures malt extracts with different diastatic (enzymatic) acivities may be produced.

Dry Milling and Flaking (Appendices 3 and 4)

In contrast to wheat, barley has a multi-cellular aleurone layer with thick cell walls. The endosperm cell walls are also thick and consist mainly of ß-glucan so the elasticity of barley endosperm is different to that of wheat. This implies difficulties in milling barley as the flour has a low ash and fibre content compared to wheat. Barley flour is much fluffier and less dense than wheat flour. It is mainly ground by roller milling. The flow diagram of the milling process is shown in Appendix 3. The initial steps of milling are to clean and moisturise the barley grain. This is achieved using separators to remove stones, sticks and other foreign material. After separating, the barley goes through an aspirator where airflow removes light impurities such as dust and straws. The next step is moisturising with intensive dampener to move the grain into the most favourable condition for subsequent grinding. Grain and fresh water are delivered together into the machine. The grain /water mixture enters a special high-speed rotor causing a uniform and intensive blend. After moisturising, the grain is ground by rollers and sieved. The fine flour is separated and coarse particles are ground for the second time. This procedure is repeated up to five times to get barley flour with different ash contents and to remove the hulls. Depending on the ash content, the flour shorts (the rejected dark fraction of the flour) may be used as feed.

Barley flours are used to bake special “flat” barley breads especially if darker barley flours are used or to bake mixed breads with wheat. Because the taste of barley is quite strong, flours with lower ash content are used. To produce barley kernels and flakes barley grains are cleaned and de-hulled. After de-hulling, kernels are either pin milled to crushed kernels or cut to produce flakes. The cut barley kernels are moisturised by steam injection and roller flaked after which the flakes are dried before packaging. The steps of barley flaking and the pin milling process are shown in Appendix 4.

Barley kernel, crushed barley and pearled barley are used as pot barley, to make porridge, pie fillings and so on. It can be cooked as an alternative to rice, pasta or potatoes, or added to stews. Barley flakes are used for porridge and gruel or as an ingredient in muesli or breakfast cereals. Barley kernels can also be used to produce “corn flakes” type of toasted barley flakes where barley kernels are pressure-cooked, flaked and toasted, or they are produced by extrusion.

Production of non-alcoholic barley beverages

Barley grains are selected to remove foreign objects. After the selection, naked barley is steamed to gelatinise the starch and dried. The processing enhances the flavour of naked barley tea. The other barleys are applied directly to roasting. Roasting is repeated two or three times at 200-280 °C until heat reaches the grain centre. The degree of roasting can be controlled by the amount of grain or the strength of heat source. According to Briggs (1978) roasting causes heat-dextrination of starch, a decline in hemicelluloses, caramelisation of sugars and formation of

melanoidins from the interaction between reducing sugars and amino acids. The consequence is development of dark colour and flavour as well as an increase in acidity and solubility of the product. Roasted barley is cooled and sieved for packaging. In order to prepare barley tea bags, the product is milled and packaged. Other than barley tea grain and barley tea bags, barley tea condensate and packed barley tea are available.

E. Typical Criteria Used to Determine Barley Quality

Barley quality criteria vary depending on its use. The most important quality parameters for different uses are discussed hereunder.

Germination

For malting purposes the most important quality parameter is a uniform germination. Normally, barley is not suitable for malting immediately after harvesting due to dormant grains. Dormancy means that grains are viable but not all of them are ready to germinate. Dormancy is common after a cool and damp season, but occurs less after a hot and dry harvesting season. Some dormancy is needed to avoid pre-germination on the field. Storage conditions affect the length of dormancy (Palmer, 1989; Riis *et al*., 1989). At least 96% of grains must germinate (Briggs *et al*., 1981). Uniform start of germination leads to homogenous modification of the endosperm. Homogeneity means in this case the synchronous germination of individual grains.

Moisture content

The moisture content is considered one of the most important quality criteria of malting barley. Wet barley respires more rapidly than dry barley, which may lead to a rise in temperature. High temperature and humidity may then activate the growth of bacteria and fungi, and lead to germination losses and production of mycotoxins. Safe storage conditions are a moisture level of 10-12% and a temperature of 15 ^{o}C (Briggs *et al*., 1981). To avoid spoilage, immediate drying of barley after harvesting is needed.

Protein and starch contents

Low protein content is preferred for malting barley, preferably between 8.0-10.5% dry matter. In general the lower the protein content is, the higher is the starch content, and thus higher the sugar content for the final malt. Proteins are partly degraded in malting and mashing to amino acids and soluble peptides, which are needed as yeast nutrients and to produce good foam of beer. A high protein content of the barley may retard water up-take during steeping and result in a high soluble protein content in wort, which may lead to a problem of haze formation in beer. Low protein content is also preferred for barley starch production to have high yields. For feed use higher protein content is desired.

Whole and minimally processed grain is fed to farm animals primarily as energy source. The most important consideration in evaluating barley for its energy value is its test weight. Higher test weights mean that the kernels have a higher starch and a lower fibre content.

Analogous to malting barley, barley aimed for starch production should have a high starch and a low protein content. The average starch content in barley grains is 60%. In the industrial

starch production process barley starch is fractionated - according to its specific weight - into two categories: starch with a large granule size and that with a small granule size. The large granule size starch is used in different modifications for food and fine paper and the small granule size starch for ethanol production. The best starch varieties used by industry are mostly composed of large granules. A loose internal grain structure is an important characteristic allowing easy separation of starch granules from other components.

Grain structure and size

Barley cell walls encapsulate starch granules embedded in a protein matrix. With thin cell walls and loose packing of endosperm, the large mealy grains allow a rapid water up-take and uniform distribution of water and enzymes synthesised during germination. On the contrary, due to thick cell walls and tightly packed endosperms, small steely grains retard mass transfer in the endosperm. Large, plumb kernels are desired for malting. The fraction above the 2.5 mm sieve is normally used for malting and the rest is included in the feed fraction. A larger uniform grain size is desired because it enables homogenous water up-take and modification.

For feed use barley grain is considered to have a poorer nutritive value than wheat or maize because of its higher fibre and consequently lower starch content. The barley hull has approximately 13% fibre, and dehulling is not practical for feed uses because the hull is fused to the seed by a cementing substance produced by the caryopsis.

Enzyme potential

Enzyme activity in barley is low or the enzymes exist in bound form. The major aim of malting is to produce or release bound enzymes to be active already during germination and later in wort production. Numerous enzymes are found in malt. The enzyme spectra needed for different uses, for example, beer or whisky-production, varies. The major enzyme groups include starch-, protein- and cell wall-degrading enzymes. The enzyme potential of barley can only be predicted after germination.

F. Comparative Analyses

This document suggests parameters that barley developers and breeders should measure when undertaking comparative analyses of new varieties of barley. Measurement data from the new variety should ideally be compared to those obtained from the near isogenic non-modified line grown under identical conditions. A developer can also compare values obtained from new varieties with data on other barley varieties or with literature values of conventional counterparts presented in this document. Critical components include key nutrients and key toxicants for the food source in question. Key nutrients are those components in a particular product, which may have a substantial impact in the overall diet. These may be major constituents (fats, proteins and carbohydrates) or minor compounds (vitamins and minerals). Key toxicants are those toxicologically significant compounds known to be inherently present in the species, *i.e.* compounds whose toxic potency and level may impact on human and animal health. Similarly, the levels of known anti-nutrients and allergens should be considered. As part of the comparative approach, selected secondary plant metabolites, for which characteristic levels in the species are known, are analysed as further indicators of the absence of unintended effects of the genetic modification on the metabolism.

The final grain composition and quality are influenced by prevailing environmental conditions (Duffus and Cochrane, 1993). Barley composition is known to vary quite markedly from one area to another, as well as from year to year within any given area. For effective comparison it is therefore important that the new variety and its comparator (that is, the control) are grown at the same site(s) (preferably in adjacent plots) and at the same time.

G. Traditional characteristics screened by barley developers

Phenotypic characteristics provide important information related to the suitability of new varieties for commercial distribution. The selection of new varieties may depend on parental data. Plant breeders developing new varieties of barley evaluate many parameters at different stages in the developmental process. In the early stages of growth, breeders evaluate stand count and seedling vigour. As plants mature, insect resistance and resistance to fungal diseases, for example, mildew, net blotch, scald, barley stripe, rusts, smuts and head blight, viral diseases and nematode diseases, are evaluated. At near maturity or maturity, heading, maturation, lodging, shedding, and pre-matured germination are evaluated. The matured plant is measured for plant height, ear height, number of shoots, ears and seeds, and yield. The harvested grain is measured for yield, moisture, test weight, shape, size, visual quality, component’s contents, malting and milling quality, and palatability.

SECTION II - NUTRIENTS IN BARLEY AND BARLEY PRODUCTS

A. Barley Grain

Whole barley grain is mostly used for feeding animals. For food purposes barley is mainly used as de-hulled grain or high fibre content products. Food produced from barley is a good source for many nutrients such as protein, fibre, minerals and B-vitamins.

The fibre content of barley is high and rich in β-glucan that is mainly soluble. Fibre rich cereals such as barley are beneficial for balancing the human diet in a manner that is of no relevance for animals. Low-digestible carbohydrates, especially β-glucan and resistant starch have a positive impact on lowering post-prandial blood glucose levels. Further, β-glucan has been reported to reduce the blood cholesterol level. Barley products are thought to be good for diabetics, obese and overweight people and for those who have a high blood cholesterol level (Kahlon and Chow, 1997). The β-glucan from barley is also known to stabilize digestion processes in young farm animals, especially in piglets (Bolduan and Jung, 1985). However, due to its viscosity-enhancing property, β-glucan causes undesirable effects in the digestive tract especially of young avians. But with increasing age of the birds the antinutritive effect decreases (Jeroch *et al*., 1993). The β-glucan levels are shown in Table 6.

Although barley has a relatively high protein content, it does not have the same baking characteristics as wheat gluten. Therefore, typical barley bread has low bread volumes. Barley flour is primarily used in combination with other flours to make multigrain breads.

The composition of barley is presented in Table 4, the proximate composition in Table 5 and the chemical composition in Table 6. The starchy endosperm consists of food reserves in the form of highly digestible carbohydrates (mainly starch), whereas the bran contains high levels of fibre and comparatively more minerals and fat than the endosperm.

Table 4.Composition of barley grain

Fraction	**% Kernel (by weight)**	**Key nutrients**
Hulls (husks)	9 – 14	Cellulose, lignin, silica, pentosan, phenolic compounds
Seed coat	5.5 – 6.5	Cellulose, lipid
Aleurone layer	11 – 13	Lipid, protein, β-glucan, arabinoxylan, minerals, vitamins
Embryo	2.5 – 4.0	Lipid, storage protein, cellulose, sugars, minerals, vitamins
Endosperm	65 – 68	Starch, protein, β-glucan, arabinoxylan

Source: compiled from Briggs, 1978; Palmer, 1989

Table 5.Proximate composition of barley grain

Parameter	% of dry matter
Protein	7.6 – 14.4
Fat	1.3 – 2.8
Crude fibre	4.0 – 8.0
Acid detergent fibre (ADF)	2.4 – 9.9
Neutral detergent fibre (NDF)	13.8 – 30.8
N-free extract	62.0 – 81.4
Ash	2.0 – 5.0

Source: compiled from Briggs, 1978; Aherne, 1990; Hunt, 1995; Bull and Bradshaw, 1995; Novus, 1996; NRC, 1998 (values converted from 89% dry matter to 100% dry matter); Anderson and Schroeder, 1999; Lardy and Bauer, 1999; USDA, 2001

Table 6.Chemical composition of barley grain

Component	% of dry matter
Carbohydrates	78 – 83
Starch	63 – 65
Sucrose	1 – 2
Other sugars	1
Water-soluble polysaccharides	1 - 1.5
Alkali-soluble polysaccharides	8 – 10
Cellulose	4 – 5
β-glucan	1 – 4
Lipids	2 – 3
Protein	10 – 12
Albumins and globulins	3.5
Prolamins (hordeins)	3 – 4
Glutelins (hordenins)	3 – 4
Nucleic acids	0.2 – 0.3
Minerals	2
Other	5 – 6

Source: MacGregor and Fincher, 1993; Lyons, 1978 (β-glucan); Marins de Sa and Palme, 2001(β-glucan)

Carbohydrates

Carbohydrates constitute the bulk of the total dry matter of the barley grain (Table 6). Most of the carbohydrate in barley is starch which serves as energy source during germination. Over 96% of the total grain cellulose is present in the hulls (husks) (Duffus and Cochrane, 1993). Mono- and di-saccharides (sucrose, glucose, fructose and maltose) are present in lesser amounts, but their concentration is twice as high as in other cereals. Of the non-starch polysaccharide fraction the content of arabinoxylan (total 6.7% of which 0.4% is water soluble; Stölken *et al*., 1996) and β-glucan (4.6%; Stölken *et al*., 1996) is of relevance when barley is fed to young monogastrics, due to the negative effects on digestion. It is noteworthy that contrary to this, the low-digestible carbohydrates especially β-glucan and resistant starch have a positive impact on human health due to their role in lowering post-prandial blood glucose levels and in reducing the blood cholesterol level.

Proteins

The proteins of barley can be divided into four solubility groups: albumins (water-soluble); globulins (soluble in dilute saline); prolamins (soluble in alcohol / water mixtures); and glutelins (soluble only in dilute acid or alkali). Prolamins, called hordeins in barley, are the major storage proteins and account for 35 to 50% of the total nitrogen in the grain. The albumins, globulins, glutelins consist predominantly of structural and metabolic proteins (Kreis and Shewry, 1992).

The protein content of barley grains varies considerably. The precise composition depends on the growth conditions and on the rate and timing of nitrogen fertilisation (Duffus and Cochrane, 1993). For this reason it is important that an appropriate comparator is used for the comparative analysis. The typical protein fractions are listed in Table 6.

In general, protein content and protein quality of barley grain are not sufficient for high-performing monogastric farm animals. Consequently their diets have to be supplemented with other protein sources. The low content of essential amino acids (*e.g.* lysine and methionine) in barley proteins is a direct consequence of the high content of hordeins that are relatively low in these amino acids. The amino acid composition of crude protein in barley grain fractions is listed in Table 7.

Hordeins have been reported to interfere with the brewing process; the amount of extract that ultimately can be derived from malt is inversely related to the protein (hordein) content of the original grain.

Table 7.Amino acid composition of barley and its fractions (g amino acid/100 g crude protein)

Amino acid	**Barley**	**Bran**	**Flour**
Alanine	4.4 - 4.6	4.1 - 5.0	3.9 - 4.4
Arginine	4.2 – 6.2	4.6 - 5.7	4.6 - 5.5
Aspartic acid	6.8 - 7.4	6.4 - 8.6	5.7 - 7.1
Cystine	1.0 - 1.79	0.3 - 2.3	1.4 - 2.1
Glutamic acid	21.9 - 26.1	20.6 - 26.6	23.3 – 28.5
Glycine	4.2 – 5.1	3.9 - 5.0	3.4 - 4.3
Histidine	1.9 – 3.3	1.4 - 2.2	2.2 - 2.4
Isoleucine	3.1 - 3.9	3.4 - 3.7	3.5 - 3.7
Leucine	5.4 - 7.1	6.6 - 7.5	6.6 - 7.0
Lysine	3.1 - 4.2	3.3 - 5.0	3.4 - 4.1
Methionine	1.4 – 3.2	1.7 - 2.3	1.6 - 2.7
Phenylalanine	4.2 - 5.4	5.1 - 5.4	5.0 - 5.5
Proline	11.4 – 12.4	9.9 – 11.9	10.1 – 12.8
Serine	3.7 – 5.4	4.4 - 4.7	4.0 - 4.4
Threonine	3.0 - 3.7	3.2 - 3.8	3.0 - 3.6
Tyrosine	1.9 - 2.8	2.5 - 3.3	2.9 - 3.2
Valine	3.9 - 5.3	4.7 - 6.1	5.2 - 5.4

Source: compiled from Bhatty, 1993; Briggs, 1978; Harrold, R. L., 1999; Bull and Bradshaw, 1995;

NRC, 1998; Ensminger et al., 1990 (values taken from the last four references were calculated from dry matter basis to % of protein, based on reported protein levels)

Vitamins

The vitamin content of barley grains varies widely. Un-germinated barley does not contain vitamins A, C and D, although the carotenoids and sterols that are present may act as precursors for vitamins A and D, respectively (Briggs, 1978). Vitamin E, a mixture of tocopherols, occurs in barley oil. Barley is unique among cereals in having all eight naturally occurring tocopherols. The tocolpherols are found exclusively in germ tissue (embryo, scutellum) and tocotrienols in the starchy endosperm and aleurone (Morrison, 1993). The tocol derivatives of barley are presented in Table 8.

Barley also contains B vitamins. These vitamins are mainly present in the embryo and the aleurone layer (Palmer, 1989). Typical ranges of B vitamin and folate concentrations in barley are shown in Table 9.

Table 8.Tocol derivatives of barley

Tocopherols	**mg/ kg Barley**	**Tocotrienols**	**mg/ kg Barley**
α-tocopherol	2.0 – 11.7	tocotrienol α-T-3	11.0 - 49.3
β-tocopherol	0.4 - 4.0	tocotrienol β-T-3	2.7 - 14.3
γ-tocopherol	0.3 – 12.9	tocotrienol γ-T-3	2.0 - 14.0
δ-tocopherol	0.1 - 0.9	tocotrienol δ-T-3	0.7 – 3.9

Source: compiled from Newman and Newman, 1992; Morrison, 1993

Table 9.B vitamin and folate content in barley grain, barley flour and malt flour

Vitamin	**Barley grain (µg/g)**	**Barley flour (µg/g)**	**Malt flour (µg/g)**
Thiamine (vitamin B_1)	1.2 – 16	3.7 - 4.0	3.1
Riboflavin (vitamin B_2)	0.8 – 3.7	1.0 - 1.1	3.1
Niacin	46 – 147	55 – 63	56
Pantothenic acid	3.7 – 4.4	1.5	5.8
Pyridoxine (vitamin B_6)	2.7 – 11.5	1.0 - 4.0	6.6
Folates	0.19 - 0.3	0.08 - 0.19	3.8

Source: compiled from Briggs, 1978; USDA, 2001; Fineli, 2001

Minerals

The major constituents of the mineral fraction of barley are magnesium, phosphorus, potassium, calcium, and sodium. The average mineral content varies significantly, and this appears to be due to a number of factors, including the variety in question, the growing and soil conditions and fertilizer application. Major constituents based on a compilation of worldwide data are given in Table 10.

A high portion of phosphorus in barley grain is bound to the phytate complex (51-66%) making much of the phosphorous unavailable to monogastric animals. Yet barley contains more

phosphorous than common cereal grains and the phosphorous bioavailability of barley is higher than that in other grains (Harrold, 1999). The amounts of copper, iron, manganese and zinc present in barley grain may vary to a large extent due to growing conditions and this has to be taken into account when diets for farm animals are formulated (Novus, 1996). As with vitamins these minerals are mainly concentrated in the embryo and the aleurone layer (Duffus and Cochrane, 1993).

Table 10. Macroelements in barley grain (86-89% dry matter)

	Ranges g/kg dry matter
Calcium (Ca)	0.4 – 0.7
Magnesium (Mg)	0.9 – 1.5
Phosphorus (P)	2.3 – 4.2
Sodium (Na)	0.2 – 2.7
Potassium (K)	3.0 – 5.9

Source: Novus, 1996; NRC, 1982 (values converted from % dry matter to g/kg dry matter); NRC, 1998 (values converted from % as fed to g/kg dry matter using dry matter value reported)

Lipids

In the mature barley grain the lipid content is approximately 3%. Lipids constitute only a small part of the dry matter in most barley tissues yet they comprise significant reserves in the embryo and the aleurone layer of the grain. They are essential for the functional integrity of the cells. The composition and distribution of lipids in the different parts of barley grain are presented in Tables 11a and 11b. The total fat content, analysed as ether extract, is presented in Tables 5 and 6.

Table 11a. Composition of lipids in the principal parts of barley grain

	Lipid class (wt %)		
Compartment	**Nonpolar lipid (NL)**	**Glycolipids (GL)**	**Phospholipids (PL)**
Whole grain	65 - 75	6 – 26	9 – 20
Embryo	76 - 90	6	18
Bran-endosperm	64 - 68	13	23
Aleurone	82	-	-
Coleorhiza	74	4	22
Coleoptile	67	6	27
Scutellum	88	3	8
Hull	76	18	6

Source: adapted from Morrison, 1993

Table 11b. Distribution of lipids in the principal parts of barley grain

Tissue	**Tissue in grain (wt%)**	**Lipid in tissue (wt%)**	**Lipid as fraction of total lipid (%)**
Whole grain	100	2-4.2	100
Embryo	3-6	19.6-24.0	17.9-37
Endosperm	88-97	1-3	63-72
Hull	6.8	2.4	5.0

Source: adapted from Morrison, 1993

The majority of the lipids in barley are acyl lipids containing the fatty acids commonly found in higher plants, that is, myristic acid (14:0), palmitic acid (16:0), stearic acid (18:0), oleic acid (18:1, n-9), linoleic acid (18:2, n-6) and linolenic acid (18:3, n-3). The typical relative fatty acid composition of barley fat is presented in Table 12.

Barley contains approximately 0.8 mg/g sterols. Barley sterols include stigmasterol, β-sitosterol, campesterol, and cholesterol (Piironen *et al*., 2000). These may occur in the free form, as glycosides, esterified with fatty acids, or as acylated glycosides. Of the sterols, β-sitosterol is the primary sterol comprising about 60% of the total sterols in barley. Campesterol is the next most abundant sterol found in barley (Piironen *et al*., 2000).

Table 12. Fatty acid composition of total lipids in barley, malt and various parts of barley grain

Anatomical part	Fatty acids (% of total fatty acids as detected)						
	14:0	16:0	18:0	18:1	18:2	18:3	Other
Barley	< 1	20 - 28	1 – 2	10 - 21	44 – 60	4 – 9	
Malt	< 1 – 2	17 - 31	1 – 3	5 – 12	48 – 65	7 – 11	
Embryo (dissected)	Tr	19 - 24	1	14 -18	51 – 56	7 – 8	
Aleurone (fraction)	< 1	20 - 21	1	12 - 15	55 – 58	6 – 7	14:1, 16:1 (1)
Endosperm (fraction)	< 1	19 - 23	1 – 3	9 – 23	51 – 62	2 – 5	
Hulls (husks)	1 - 6	20 - 40	1 – 5	10 - 20	43 – 50	7 – 16	16:1 (1 - 4)
Bran	1	21	1	13	57	6	16:1 (tr)

Source: adapted from Morrison, 1993; NRC, 1994 (values only for barley grain calculated from per cent as fed to per cent of fatty acids by totalling the fatty acids and dividing each by the total)

B. Whole plant

In addition to the production of grains, immature barley plants are used for forage, pasture or hay. The typical constituents in barley silage and straw are shown in Table 13. However, depending on the harvesting stage the crop quality and composition may differ considerably. For example when harvested at the dough stage the dry matter content may be between 28-42% and the crude ash content 6.2-7.7% of dry matter (Jaakkola *et al*., 2001, 2003).

Table 13. Chemical composition of barley whole plant silage (18.5-39% dry matter) and straw (86-91% dry matter) from barley

	Whole plant silage (g/kg of dry matter)	Straw (g/kg of dry matter)
Proximates:		
Ash	75 –188	64 – 75
Crude protein	67 – 120	38 – 44
Crude fat	29 – 39	17 – 19
Crude fibre	356 –568	420 – 438
Acid detergent fibre (ADF)	345	590
Neutral detergent fibre (NDF)	563 – 568	725
Minerals:		

Calcium	4.8 - 6.0	3.0
Phosphorus	3.0 - 3.3	0.7 - 0.8
Magnesium	1.4 – 1.8	0.9 – 2.3
Potassium	24.3 - 29.5	23.7
Sodium	1.3 - 1.5	1.4 - 3.7

Source: Jeroch et al., 1993; NRC, 1982, 2000, 2001

C. Processing By-Products

By-products from the dry milling of barley and from the beer and malt industry have long been employed as ingredients in animal feeds. According to the processing technology and the extraction rate various classifications of barley by-products from dry milling are possible. Maltsters' pellets, brewers' grains and brewers' yeast are by-products from the brewing industry. Brewers' grain is a bulky by-product including spent grain and hops. The principal by-products from the brewing and milling processes (see flow diagrams in Appendices 2 and 3) and their mean chemical composition are listed in Table 14.

Table 14. Crude nutrients in processing by-products (g/kg dry matter)

	High grade feed*	Bran	Low grade feed**	Hulls	Malsters' pellets (sprouts and hulls)	Brewers' grains	Brewers' yeast
Crude ash	43	5	78	71	66	49	85
Crude protein	138	137	111	85	296	244	530
Crude fat	34	38	37	44	10	79	20
Crude fibre	81	140	209	276	164	177	15

Source: Kling and Woehlbier, 1983; Jeroch et al., 1993

* By-product obtained from processing of screened and dehulled barley into pearl barley

** By-product obtained from processing of screened barley into pearl barley

SECTION III - ANTI-NUTRIENTS AND OTHER COMPOUNDS IN BARLEY AND BARLEY PRODUCTS

A. Anti-nutrients

The content of common anti-nutrients in cereals, including barley, is considered to be low when compared with legumes such as faba beans, peas and lupines.

Protease and Amylase Inhibitors

Protease inhibitors, especially trypsin inhibitors, may decrease the digestibility and nutritional value of ingested protein and retard growth when sufficient amounts are present in the diet. Amylase inhibitors may affect the digestibility of starch (Aherne, 1990). Both protease and amylase inhibitors have been identified in barley (Palmer, 1989). 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.

Amylase inhibitor accumulates in barley grain during grain development (Duffus and Cochrane, 1993). Chymotrypsin inhibitors are present in the starchy endosperm and the aleurone layer (Kreis and Shewry, 1992).

Lectins

Lectins, sometimes called phytohemagglutenins, 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. Although more commonly associated with legumes, cereal grains including barley are also known to contain lectins. However, their potential for physiological significance is unknown (Liener, 1989).

Phytic acid

Phytic acid (myo-inositol hexaphosphate) chelates minerals such as iron, zinc, phosphorus, calcium, potassium and magnesium. The bioavailability of these minerals 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 effect on potassium, phosphorus or magnesium assimilation. Ruminants, on the other hand, are more readily able to utilise phytate-complexed phosphorus because they have abundant amounts of microbial phytase which degrades phytate in the rumen (Harland, 1993). Bull and Bradshaw (1995) report phytic acid levels ranging from 0.70-0.76% for barley grain.

Hordeins

Barley, along with other gluten-containing cereals such as wheat and rye, is also associated with a condition known as gluten-sensitive enteropathy (also called coeliac disease), which affects genetically predisposed individuals (FAOSTAT data, 2004). Gluten is a complex of two major storage proteins in cereals namely prolamin (hordeins in barley, gliadins in wheat) and glutelin

(hordenins in barley, glutenins in wheat). The sensitivity response is triggered by the prolamin fraction of the cereal storage proteins that are hordeins in barley (gliadins in wheat).

B. Other compounds

Barley also contains a number of other constituents, some of which, at higher intakes, have been suggested to have a role in protection against diseases (Thompson, 1994). These include simple phenolic acids, lignans, and the flavonoids.

Ferulic, vanillic, *o*- and p-coumaric, syringic, *p*-hydroxybenzoic, sinapic and chlorogenic acids occur free in barley. Water soluble esters of *p*-hydroxybenzoic, protocatechuic, ferulic, vanillic, p-coumaric, syringic, caffeic, sinapic and isoferulic acids have been detected as have glycosides of several of these and of gentisic, chlorogenic and dihydroxybenzoic acids (Briggs, 1978). Phenolic acids, principally ferulic but also p-coumaric acid, are covalently associated with arabinoxylans and constitute approximately 0.05% of cell walls in the starchy endosperm and 1.2% of aleurone walls. The insoluble, bound p-coumaric acid of barley grain is concentrated on the outer grain layers (McGregor and Fincher, 1993). 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. The phenolic acids are good antioxidants (Rice-Evans *et al*., 1997).

The flavonoids are a large group of phenolic compounds that occur widely in plants, and many of them have good antioxidant properties. Barley contains a range of flavonoids. Catechin, epicatechin, anthocyanins and proanthocyanins also occur in barley grains (Briggs, 1978).

Barley also contains phytoestrogenic compounds, that is, isoflavones and lignans. Minor amounts of isoflavones are present in barley (Murphy and Hendrich, 2002). Lignans are phenolic dimers, which are predominantly present in the bran. Lignans are converted by fermentation in the large intestine to mammalian lignans (Thompson, 1994). The plant lignan secoisolariciresinol occuring in barley is converted by intestinal microbes into enterodiol and enterolactone (Murphy and Hendrich, 2002).

SECTION IV - FOOD USE

A. Identification of Key Barley Products Consumed by Humans

Some 140 million tonnes of barley is produced annually worldwide (FAOSTAT, 2004). In industrialised countries the consumption of barley as food has lost most of its earlier importance in human nutrition (Fischbeck, 2002). The strong taste and "gummy" mouth feeling of whole barley kernels is limiting its food use. The major products are whole and crushed or pearled barley kernels, flours and flakes.

The predominant food product of barley is malt that is primarily used in the brewing industry. Barley malts, malt extracts and syrups are used in small amounts in food products to give better flavour and colour, for example, in breakfast cereals and baked goods. The largest use is in fermented bakery products. Malt extract is a source of soluble sugars, protein and amylase in the dough and promote the activity of yeast resulting in good bread texture and bigger loaf volume, good flavour and colour to the finished baked products. Further applications of malt products are for non-fermented bakery products, for example, crackers, cookies and muffins. Malted barley rich in enzymes is also used for bakery products as a source of amylases to compensate the low α-amylase activity in bread wheat flours.

Although most of barley starch is used for manufacturing fine-quality papers it also serves as good raw material for the food industry, where it is used as sweetener and binder. In the brewing industry, barley starch is used, together with barley malt, in the production of beer. Starch fermentation products are also distilled to pure grain alcohol for vodka-type products as well as industrial ethanol that is sold mainly to the pharmaceutical industry.

Modest quantities of non-alcoholic drinks based on barley and malt are consumed in various parts of the world. Both barley and malt are roasted and hot water infusion of the whole or ground products are consumed. Examples of such beverages are 'malt coffee' or 'barley tea'. 'Barley water' is made by soaking pot or pearled barley. There are also various malted beverages available, often in the form of 'malty milk' in which malt extract is blended with milk. The mixture is dried and sold as soluble powder (Briggs, 1978). 'Barley tea' is consumed in many Asian countries. Six-rowed barley, two-rowed barley and six-rowed naked barley are processed to barley tea in Japan. Furthermore, there are some minor food products such as barley germ-oil used as a food supplement or barley sprouts that are occasionally consumed. Both are of limited importance in the human diet.

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

The suggested key constituents to be analysed for human uses of barley are shown in Table 15. As all food products are derived from the whole grain it is considered sufficient, in most circumstances, to analyse key constituents of kernels only. In the production of malts the seeds undergo a germination process activating the formation of a number of enzymes that in turn have a role in mobilising the seed reserves and enhancing the brewing process. The major enzymes

produced during germination are starch-, protein-, and cell wall-degrading enzymes. Therefore, depending on the nature and purpose of the specific modification, additional analyses of different fractions may also be useful.

It is not yet clear to what extent lectins, trypsin inhibitors and amylase inhibitors may be significant anti-nutrients in barley. However, it would not be desirable for their levels to be increased. The literature is not abundant with reference values and therefore the suggestion that these constituents be measured should remain optional.

Table 15. Suggested constituents to be analysed in barley for food use

	Whole grain	Flour	Malt
Proximates [a]	X	X	X
Starch	X	X	X
β-Glucan	X	X	X
Amino acids	X		
α-Tocopherol	X		
B vitamins	X	X	

[a]: Proximates include protein, fat, crude fibre, ash and nitrogen-free extracts (sugars, starch, soluble fraction of hemicellulose).

SECTION V - FEED USE

A. Identification of Key Barley Products Consumed by Animals

The key barley products used in animal feed can be divided into three categories: (i) whole and minimally processed grain, (ii) whole plant forages; and (iii) by-products of processing.

Whole and Minimally Processed Grain

Whole and minimally processed grain is fed to farm animals primarily as an energy source and also to supply protein, vitamins and minerals. Barley is the most widely cultivated animal-feed cereal throughout Europe. As to the high digestibility it can be used most effectively in pig feeding, but it is also a valuable component in concentrates for ruminants and poultry (Kling and Woehlbier, 1983).

Most barley for animal feed is derived from winter varieties, which are somewhat higher in crude fibre and correspondingly lower in their energetic feeding value as compared to the summer varieties, which are predominantly used for brewing. However, in years in which growing conditions affect the quality of brewers' barley adversely, significant quantities are then used for animal feed (De Boer and Bickel, 1988). There are no known feed restrictions for barley grain in animal diets (Hoffmann, 1997).

The most important consideration in evaluating barley for its energy value is its test weight (that is, weight per bushel). Barley batches with higher test weights are higher in starch and lower in fibre. Some have observed that the two row varieties of barley have a tendency to be higher in starch and lower in fibre, though compositional analysis has not revealed any major differences (Boyles *et al*., 2002).

Barley is a valuable grain for "finishing" beef cattle in the United States. Most barley is subjected to processing to break or alter the hard shell so that the barley is more amenable to animal digestion. Common processing techniques include grinding, cold rolling, moist rolling (16% moisture), tempering (soaking 24 hr. in water) and rolling, steam rolling and steam flaking. With processing its energy value is slightly less than maize because of the higher fibre, but it has more protein (Boyles *et al*., 2002).

Barley is used in swine diets, especially in those geographic regions where maize cannot be economically produced. In these regions, it competes with wheat as a feed, though it is considered to have a poorer nutritive value because of its higher fibre content. The barley hull has approximately 13% fibre, and dehulling is not practical for feed uses because the hull is fused to the seed by a cementing substance produced by the caryopsis. Dehulled varieties have been developed, but even though the composition looks attractive from its higher amino acid content, especially in respect of lysine, variable results have been obtained in feeding trials. It has been postulated that β-glucans, structurally similar to cellulose, are part of the cause of variable animal performance observed. However, the exact role of these substances has not been confirmed through research.

Whole Plant

In the last decades whole plant silage is becoming a more important feed for ruminants as well as for other species (Jeroch *et al*., 1993). For this production type winter and summer varieties are used, sometimes sown in combination with a fast-growing grass variety. In addition, the straw as a by-product of the harvested grains can be used as low-quality forage for ruminants. The whole plant silages are high in fibre and low in protein and may be used in extensive cattle production, to provide some nutrients.

By-Products of Processing

The amount of milling by-products used in animal feed is probably a function of the demand for flour, grouts and pearl barley. These barley products are predominantly used in nutritional products for human consumption (Becker and Nehring, 1967). By-products of the dry milling of barley have long been employed as ingredients in animal feeds. Generally millers remove 80-83% of the kernel for flour and the rest goes into the production of livestock feeds (Becker and Nehring, 1967).

In milling by-products resulting from pearl barley production the residues amount to 50-60% of raw barley. The individual by-products have largely lost their identity during the milling process. The by-products from the various production steps are combined in a single product (generally termed "barley feed") that is sold to the feeding industry. Individual by-products are not generally marketed (Becker and Nehring, 1967).

The predominant criterion for the feeding value of the milling by-products is the fibre content, as the digestibility of total nutrients is negatively affected by this fraction. Accordingly, low-grade barley feed and hulls are poor quality feeding stuffs for monogastric farm animals (Kling and Woehlbier, 1983).

By-products from brewing, such as brewers' grain is also known as valuable feeding stuffs. As their moisture content is very high they are mostly fed fresh to cattle and dairy cows. After drying they may also be used as constituents of concentrates for poultry (Jeroch *et al*., 1993). Depending on economic value the various brewers' by-products are sold separately or as mixers with grains. Consequently, brewers' grains vary considerably in their chemical composition.

Brewers' grain is a bulky by-product of the beer or malt industry and the product includes spent grain and hops. It is a good source of by-pass protein for dairy cattle but is low in calcium and phosphorus. Intake is limited to 20-25% of the grain mixture dry matter and 15-25% of the total ration dry matter. It has a short storage life of 2-5 days in summer and 5-7 days in winter. Because of its bulkiness and cost, distribution is usually limited to a distance of 167 – 333 km from the brewery (Amaral-Phillips and Hemken, 2002).

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

The composition of grain, the by-products of processing and the whole plant appear to be representative of all the products that could be fed to animals. The nutritional and compositional parameters of barley, which are of importance for animal feed use, are shown in Table 16.

Analysing either whole grain or by-products of processing will provide equivalent information on these parameters.

It is not yet clear to what extent lectins, trypsin inhibitors and amylase inhibitors may be significant anti-nutrients of barley. However, it would not be desirable for their levels to be increased. Because the literature is not abundant with reference values, the suggestion that these constituents were measured should remain optional.

Table 16. Suggested constituents to be analysed in barley for feed use

	Whole grain	Processing by-products	Whole plant
Proximates	X	X	X
Amino/acids	X	X	
Phytic acid	X		
β-Glucan	X	X	

The key analysis for animal feeds is the proximate analysis. Feeds are typically evaluated in terms of six components: dry matter; crude ash (mineral matter); crude protein (N x 6.25); crude fat (ether extract); crude fibre (composed of cellulose, hemicellulose and lignin); and nitrogen-free extracts (starch, sugars, soluble fraction of hemicellulose). For proximate analysis of animal feeds, acid-detergent fibre (ADF) and neutral detergent fibre (NDF) are preferred to crude fibre analysis. They give an improved indication of the digestibility and the energetic feeding value of the feed, which is particularly important for feed evaluation.

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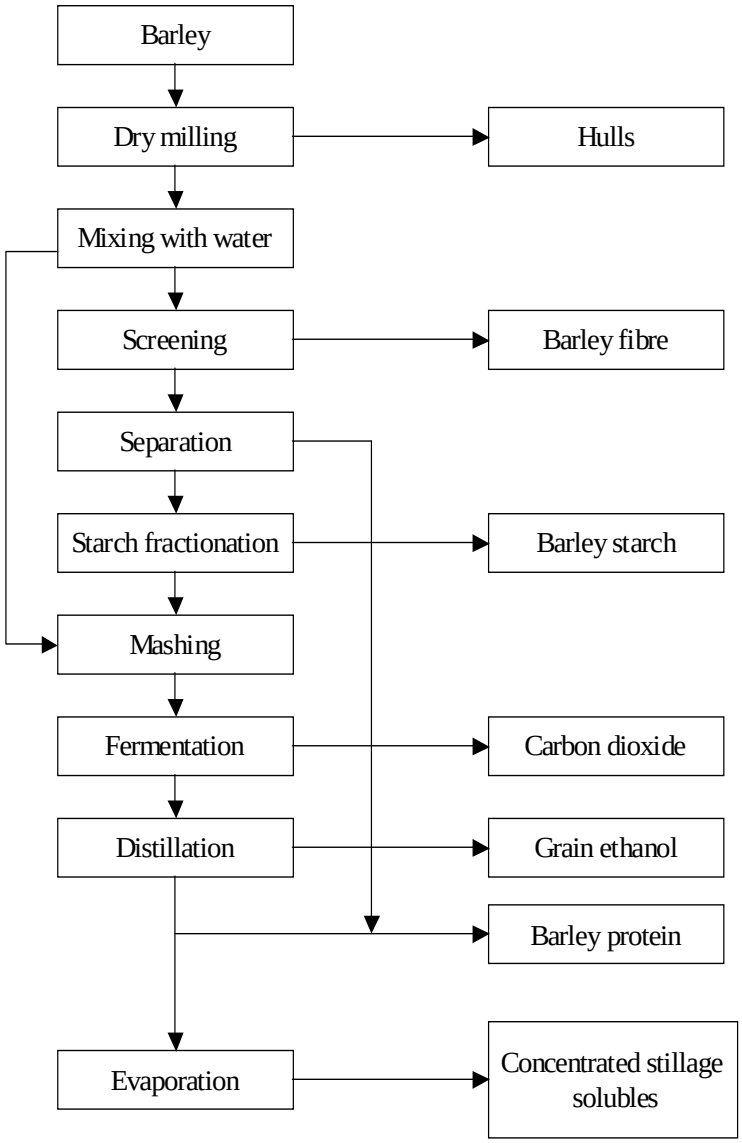
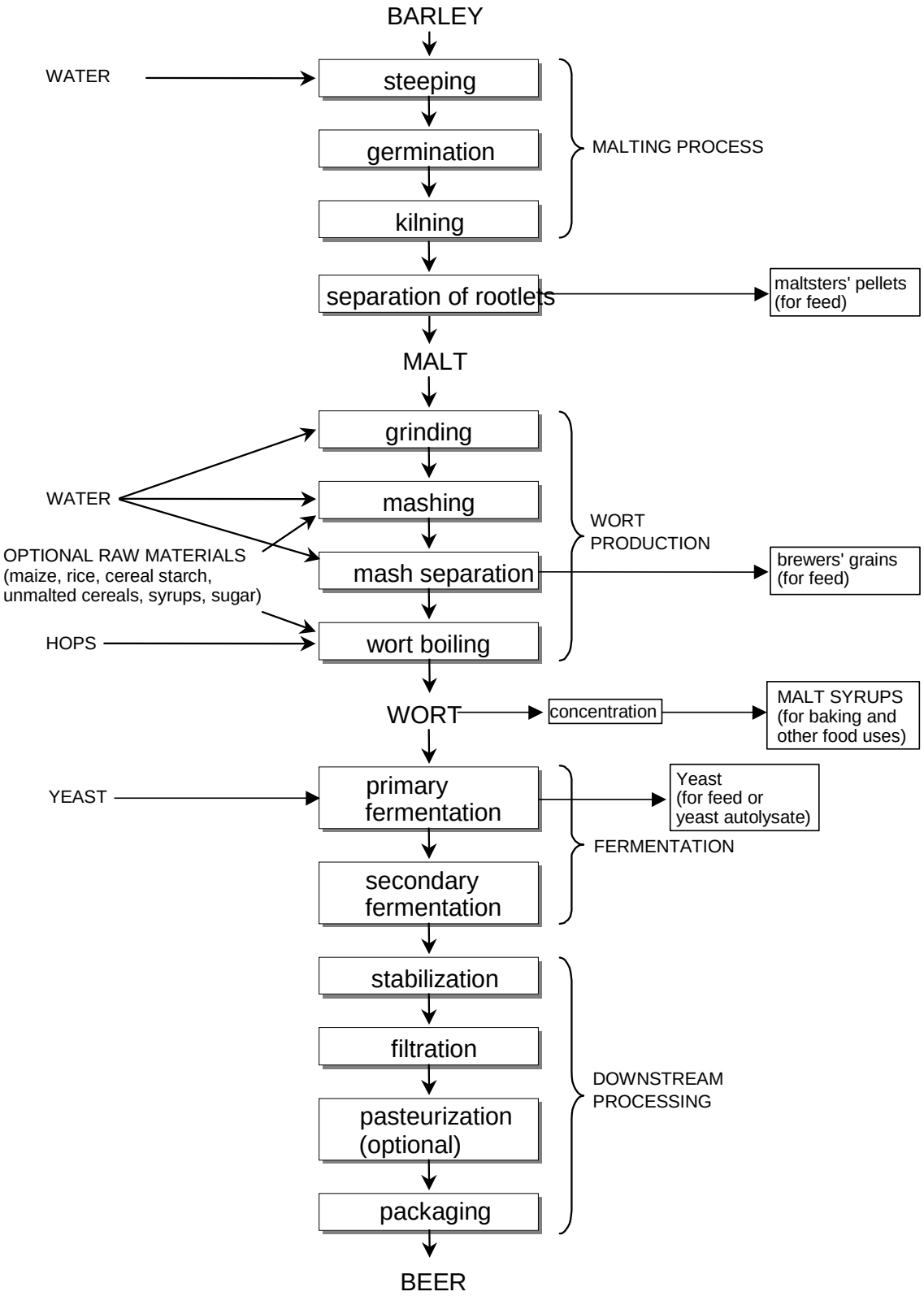
Appendix 1

Barley fractionation for starch and ethanol production

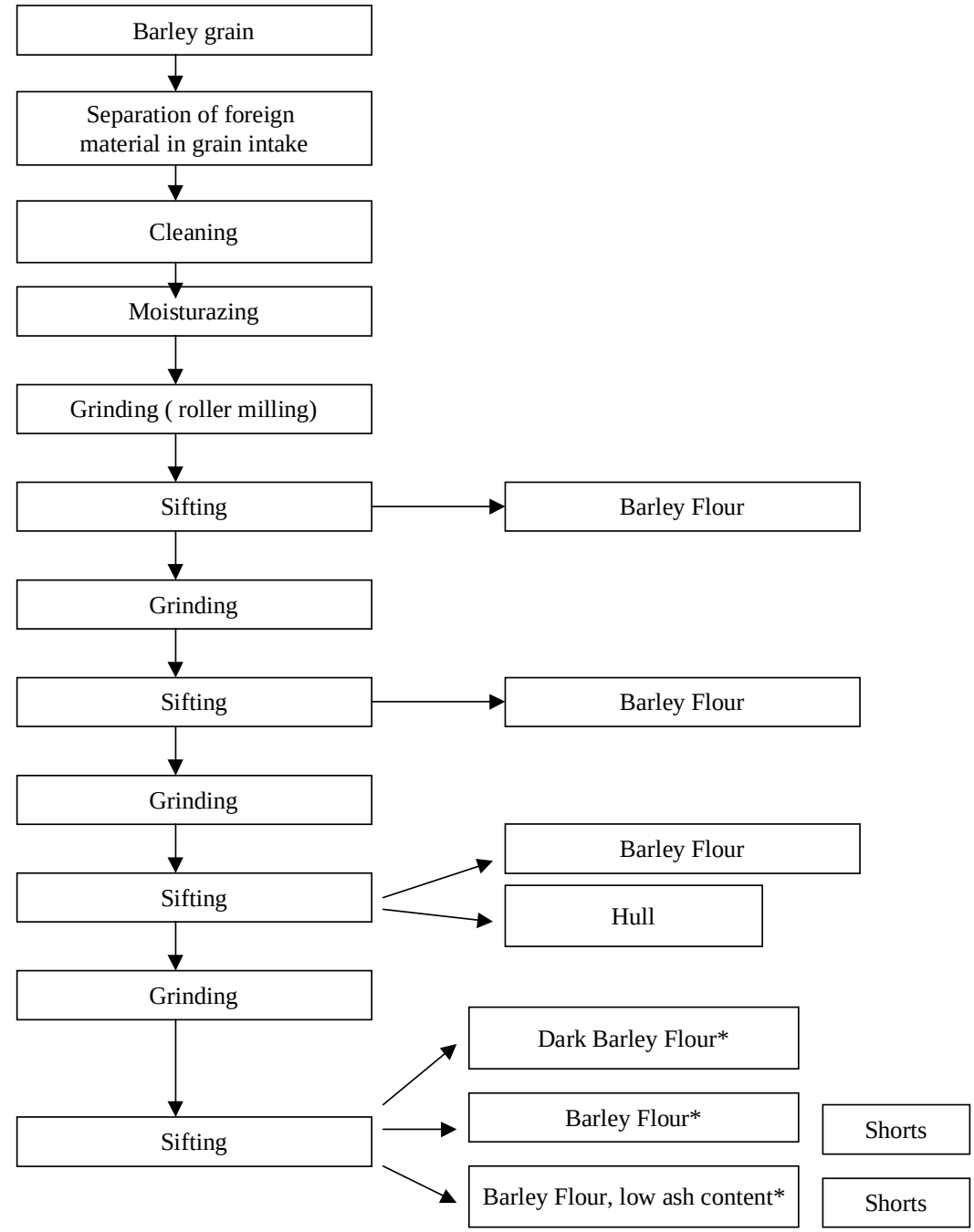


Appendix 2

Overview of malt, beer and malt syrup production steps



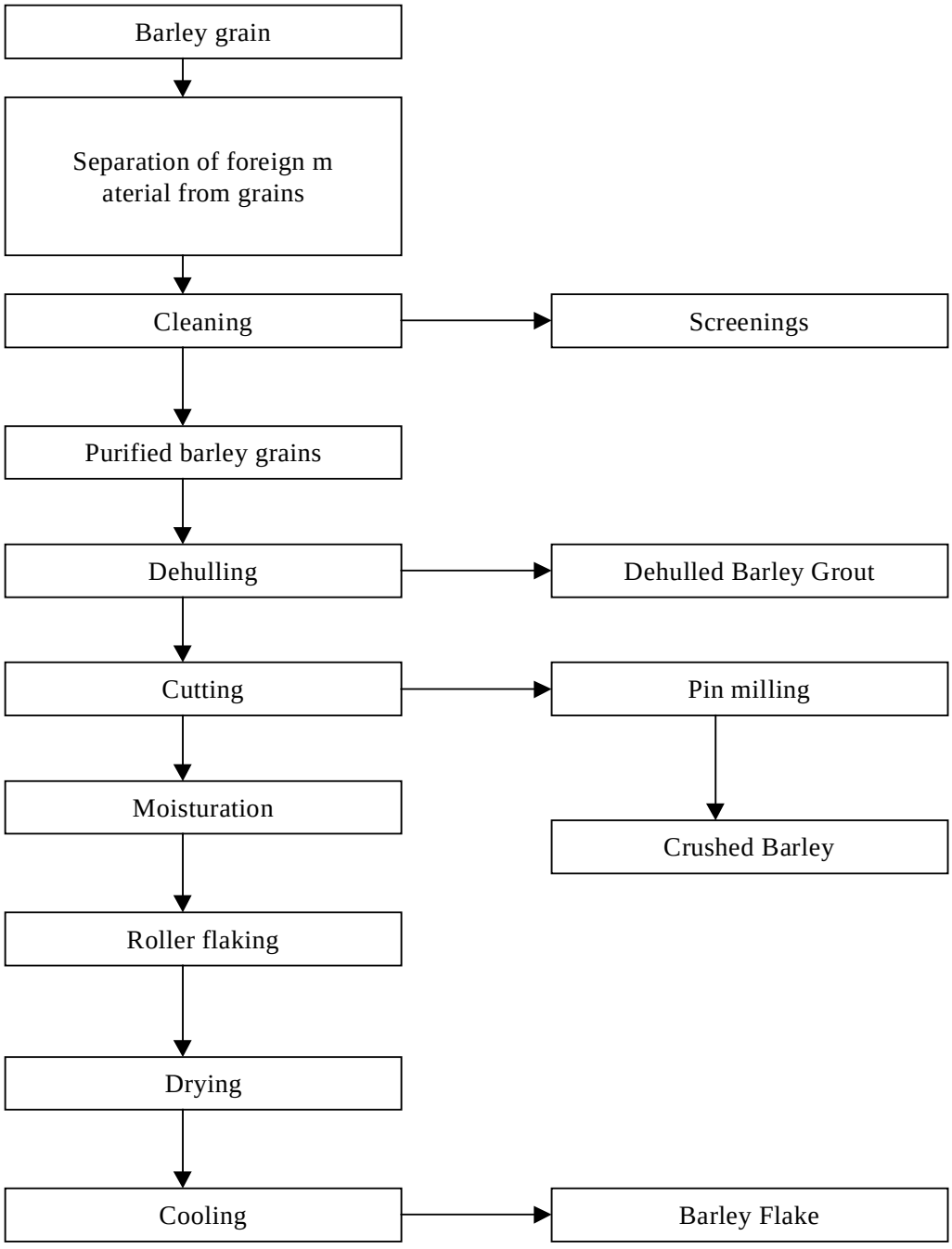
Appendix 3
Barley flour milling



- When milling dark Barley Flour (ash content between 1.2 - 1.3 %), no shorts is taken
- When milling Barley Flour (ash content between 1.0 - 1.2 %), some shorts is taken for feed use
- When milling low ash content Barley Flour (ash content below 0.9%), more shorts is taken for feed use

Appendix 4

Barley flaking process



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