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Review

GRAIN QUALITY TRAITS IMPORTANT IN FEED BARLEY

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*Spring barley (*Hordeum vulgare *L.) traditionally has been a major cereal crop for animal feed especially in Northern areas and also in Latvia. It is complicated to define what the ideal feed barley should be, as the requirements widely differ not only for different species, but even for different age groups of the same species of animals. Therefore, the breeding of feed barley has been developing very slowly and building on the basis of agronomic and beer barley quality parameters. Targeted breeding of barley varieties for a definite application purpose of the grain is connected with selection according to different criteria. The present article shows that the feed quality of barley is influenced both by physical grain quality indicators (colour, grain weight and size, hull content, 1000 grain weight, volume weight and grain hardness) and by the chemical composition (carbohydrates, non-starch polysaccharides, amino acids, fibre, protein, fat, minerals and vitamins). On the basis of the information collected, a profile of a high quality feed barley variety for different groups of animals is defined.*

Key words: *spring barley, traits of feed grain quality, breeding.*

INTRODUCTION

Spring barley (*Hordeum vulgare* L.) is a crop with a wide range of application. Barley is mainly cultivated for the animal feed, food and beer production industries. Barley is a major cereal crop for animal feed, especially in Northern areas, which are unsuitable for corn cultivation. Thus, barley constitutes the main source of feed in Canada, North America and Europe. Spring barley traditionally has been a major cereal crop also in Latvia, enjoying the highest application as a concentrated feed ingredient for agricultural animals compared to other cereals.

The leading exporting countries of feed barley are the Ukraine, Russia, Australia, European Union and Canada (Anonymous, 2012). The quality requirements for grain from the processing industry are the most clearly defined concerning grain used for malt production. Prices of feed barley depend mainly on the following indices: coarseness and uniformity of grain, grain purity and presence of grain damaged by diseases, i.e. the demanded quality parameters do not reflect the energy or nutritional value of grain. One of the problems is diversity of the quality conditions set by the users of feed grain. The required quality is highly dependent on the species of animal. The processing methods applied before the final use of grain for animal feed also have an effect on these requirements. Consequently, there are no unified quality requirements in place for feed grain, which hinders the formulation of unified quality standards. The grain processing enterprises and other buyers of grain in Latvia also apply only quality parameters, like grain purity, volume weight and moisture content. There are no specific quality criteria exclusively set for feed grain. Normally, all grain failing to meet the standards set for food grain is automaticaaly qualified as suitable for feed.

Barley is used for animal feed largely to meet the energy needs of agricultural animals. For cows, pigs and poultry, barley, apart from being an energy source, constitutes also a protein source (Hunt, 1996). Also barley used for malt, for example, has to be able to provide yeast fungi with the required energy in the process of fermentation. Therefore, high energy value is a decisive indicator for both beer and feed barley (Ulrich *et al*., 1996). Nevertheless, up to now, feed barley breeding in the world has been strongly guided by agronomic and physical indicators, such as yield and volume weight. This is the reason why breeding of feed barley has been developing very slowly, building on the basis of agronomic and beer barley quality parameters. One of the reasons is the excessively high costs of animal feed trials. The raw material purchasing policy of the grain mills commonly relating the grain price solely to the volume weight was another disincentive consideration hindering the development of the feed barley breeding sector.

It is complicated to define what the ideal feed barley should be, as the requirements in place highly differ not only among species but even for different age groups of the same animal species. High yield for feed varieties is an important indicator, while from the financial point of view, grain quality is an increasingly important factor for grain producers as the price of feed ingredients among other parameters is largely influenced by the cost of the final product.

Targeted breeding of barley varieties for a definite application purpose of the grain is connected with selection according to different criteria, because "grain quality" is a complex of quantitative characteristics depending on the physical parameters of grain and their chemical composition. The use of barley grain for feed, which is distinguished by specific chemical composition, will increase the utilisation efficiency of grain and also reduce environmental pollution with chemical compounds indigestible by the animals. The quality of barley feed is determined both by physical and chemical criteria in a complex interaction and also by feeding quality of the feed barley grain.

The aim of this paper is to define a profile of a high quality feed barley variety for different groups of animals on the basis of information reviewed in scientific literature.

TRAITS OF PHYSICAL GRAIN QUALITY

Grain colour. The barley grain (caryopsis) consists of hull, pericarp, seed coat, aleurone layer, sub-aleurone layer, endosperm and germ (Evers *et al*., 1999). The quality of the feed barley is characterized by the colour of grain. The aleurone layer of grain consists of three layers of cells, constituting 5% of the dry matter of grain and is composed mainly of proteins, minerals and vitamins. Depending on the colour of the aleurone layer, which is determined by the presence of phenol-containing pigments, the grain may have black, purple, blue, green or yellow colour (Evers *et al*., 1999). According to the research of J. Fregeau-Reid *et al.* (2001), barley lines with purple-coloured lemma contain up to 10–16% higher crude protein content and 5% higher β-glucan content than in genotypes with a yellow lemma. Barley lines with yellow grain colour have relatively higher starch and fibre content than in genotypes with yellow lemma. The authors point out that purple lemma could be used as a selection criterion for reduced fibre content in grain.

The dark colour of both, covered and hulless (naked) barley is imparted by tannins present in the aleurone layer or the water-soluble polyphenol compounds (Evers *et al*., 1999). It has been established that these compounds limit the growth and development of micro-organisms found in the intestinal tract of some agricultural animals; bound to proteins and polysaccharides they delay the functions of digestion enzymes. Tannin-protein molecules are too large to be absorbed by the gastro-intestinal tract of the animal. Grain with a dark aleurone layer absorbs moisture very slowly limiting contact of the enzyme with nutrients contained in grain, thus impairing the digestibility of grain for all categories of agricultural animals. Poultry birds are practically incapable of digesting whole, unmilled barley grain. Moreover, tannins impart an astringent flavour to the feed, which is disliked by most domestic animals (Shirley, 1998). Thus, barley grain with low tannin content, i.e., of light colour, is much more suitable for feed, especially as poultry feed. The tannin content in barley constitutes about 0.7%, in wheat — 0.4% and sorghum — 1.5% (Evers *et al*., 1999).

Hull content. The hull content of barley constitutes up to 13% of the weight of grain, and the weight varies from 7 to 25% depending on genotype, growth conditions and coarseness of the grain (Evers *et al*., 1999). The hull consists mainly of cellulose, hemi-cellulose and lignin (Munk, 1981). The hull contains more than 96% of the total cellulose found in barley (Andersson *et al*., 1999b). The final phases of the grain maturation limit field sprouting (pre-harvest sprouting) of barley. At the time of harvesting, the hull protects the germ during the abrasive threshing process in the harvester (Olkku *et al*., 2005). The proportion of hulls increases the fibre content of grain, reducing the amount of metabolizable energy (Bell *et al*., 1983). Also R. Bhatty (1986) notes that exclusion of barley hulls from the diet may increase the digestible energy of barley by 10–15%. The study of C. Darroch *et al.* (1996) demonstrated that mechanical addition of hulls to hull-less barley reduced protein digestibility. Energy digestibility of grain of the hulless cultivar 'Condor' was 87.4%, compared to 68.1% digestibility of a mix of grain and hulls (20% hull admixture) . The protein digestibility was reduced from 88.6% to 63.3%, respectively. From this viewpont, hull-less barley has an advantage over the hulled barley.

Grain weight and size. The physical traits of grain closely depend on the concentration of specific nutrients in the grain, and therefore, since the beginning of breeding, grain breeders have worked on targeted selection to increase the weight and size of grain and thus improve productivity and other commercial indicators of the variety (Rodomiro *et al.,* 2002; Pasarella *et al*., 2005). Grain weight and size are important quality indicators both for malting and feed barley. The grain size or uniformity of grain is determined by sieving to obtain four fractions: $<2.2 \times 20$ mm (sharps), $>2.2 \times 20$ mm, $>2.5 \times 20$ mm, and $>2.8 \times 20$ mm. The smaller grain usually have lower starch level and relatively higher protein content, resulting in reduced extract outcome (Edney, 1996). Therefore, coarse and uniform grain (percentage of grain above the 2.5 mm sieve) is an important criterion set by maltsters and brewers of different countries. The improvement of this trait is included in different genetic improvement programmes of barley (Henry and Cowe, 1990; Fox *et al*., 2006)., Coarse grain that is richer in starch ensures a higher feed quality (Edney, 1996). The study of C. Elfverson *et al.* (1999) however, did not indentify any significant difference in starch content among different fractions of grain, and a slight reduction of starch content with increase of grain size was even observed. In the same way, the protein content in different grain fractions differs slightly. The correlation between grain size and β-glucan content has been established, which has been explained by thicker endosperm cell walls. 1000 grain weight is a physical indicator of grain commonly used in breeding for characterisation of grain weight (Andersson *et al*., 1999b). Fairbairn *et al.* (1999) proposed to use the above indicator for the energy value assessment of grain, as it showed significant ($P < 0.01$) correlation with digestible and metabolizable energy. Volume weight of grain is an indicator used in many countries, including Latvia, to characterise feed barley grain quality. Cultivars with coarser and heavier grain have higher volume weight (Andersson *et al.*, 1999b). With a reduction of the volume weight of barley grain, the fibre content increases and the starch content declines. Therefore, the volume weight of grain is considered to be a relevant indicator for relative feed value and is recommended as a criterion for setting the feed grain price. However, studies by some researchers have demonstrated that barley with reduced volume weight has the same feed value as that of normal volume weight (Christison and Bell, 1975). Therefore, the real feed value of lightweight barley remains unclear. From the point of view of grain processing, barley samples with lower volume weight contain more shrivelled-form grain, which is more complicated to process than grain of normal or high volume weight.

Grain hardness. Up to now, grain hardness as a trait has enjoyed only limited application as a quality descriptor of barley grain. As hardness characterises endosperm structure, this parameter is usually applied for wheat quality assessment (Darlington *et al.*, 2000). Based on this indicator wheat is classified into hard wheat and soft wheat (Greenwell and Schofield, 1986). The hardness of endosperm can be measured in different ways. It can be expressed as particle size, μm (Beecher *et al.*, 2002), as a Hardness Index in the Single Kernel Characterisation System/SKCS (Gaines *et al.*, 1996) or as a milling energy indicator, J — amount of energy used to mill the sample (the harder the grain, the higher energy consumption) (Wrigley, 1999; Camm *et al.*, 2005).

Some studies have demonstrated that the grain hardness of barley can critically impact grain quality. It reflects a complicated correlation among the structural components of endosperm: starch, protein and β-glucan (Darlington *et al.*, 2000). The quantitative trait locus (QTL), which is mainly responsible for the grain hardness trait, is found in the 7^{th} chromosome of the barley genome (Beecher *et al.*, 2002), and is influenced by the genes *hin a*, *hin b-1*, and *hin b-2* (Fox *et al.*, 2007; Turuspekov *et al.*, 2008). Grain hardness was observed to be relatively higher in barley genotypes with both high and low amylose content in grain (Jagtap *et al.*, 1993). G. Camm *et al.* (2005) found that varieties with higher protein content had harder grain. The use of barley varieties with softer endosperm is recommended in brewing (Holopainen *et al.,* 2005), while barley with harder endosperm is better used as feed (Beecher *et al.*, 2002).

TRAITS OF CHEMICAL GRAIN QUALITY

The primary role of nutrients contained in feed is to ensure the life processes of an animal. Animals utilise nutrients as structural material and as a source of energy for regulation of body functions, activities and reproduction. Mature barley grain usually contains 80 to 90% dry matter. The dry matter of all feed, including barley, consists of both organic and inorganic substances (Osītis, 1998). Organic matter includes substances containing nitrogen (crude protein) and substances having no nitrogen in their composition (carbohydrates, crude fat, vitamins).

Carbohydrates. The energy value of barley largely depends on its starch content and less on indigestible fibre components, such as cellulose, lignin and non-starch polysaccharides, β-glucan and arabinoxylan (hemicellulose) (Newman and Newman, 1992b). Starch constitutes the largest part of endosperm and usually amounts to about 62% of barley grain dry matter (Evers *et al.*, 1999) and varies in the range from 53 to 67% (Amans, 1985). Starch is composed of polymers — amylose and amilopectin (Mauro, 1996). The amylose/amylopectin ratio in starch is determined by genetic factors. The gene controlling waxy starch (*wx*) is located in the 7^{th} chromosome of barley. It determines formation of starch having 96–100% amylopectin in its composition. The formation of high-amylose (35–45%) starch is controlled by the gene *amo 1* located in the 7^{th} chromosome of the barley genome (Xue *et al.*, 1997; Washington *et al.*, 2000). Through combination of both the above genes, genotypes with average amylose content are obtained (Washington *et al.*, 2000). The alleles of the gene controlling waxy starch can be transferred either by backcrossing or by applying mutagenic methods (Swanston, 1997). The diverse chemical structure and relations of amylose and amylopectin determine the properties of starch (Manner, 1985; Song and Jane, 2000). The molecule of amylase is long with a linear shape, while that of amylopectin is short and branchy (Song and Jane, 2000). For the majority of barley varieties, starch contains 70–80% amylopectin and 20–30% amylose, i.e. ratio 3 : 1. Significant differences in chemical composition have been found for the hulless genotype: normal or high amylose content. For genotypes with high or low amylose content the crude protein content in grain is usually higher (Oscarsson *et al.*, 1997). As their endosperm cell walls are relatively thicker, their β-glucan content in grain is higher than that of conventional barley (6.4% and 4.8%, respectively) (Ullrich *et al.*, 1996). In a study on barley varieties with waxy endosperm Izydorczyk *et al.* (2000) found that the average β-glucans content in grain was 6.30% (4.38% for ordinary barley). The β– glucan content of the hulless waxy genotype cultivar 'Provashanupana' is 14.9% (Andersson *et al.* (1999a). Hulless waxy genotypes are usually distinguished by a very high crude fat content (6.06–6.81%) and a relatively high crude ash content of grain (2.33–2.36%) (Andersson *et al.*, 1999a; Li *et al.*, 2001).

In grain endosperm, starch is accumulated in the form of pellets (tiny grains) encapsuled in a protein matrix (Morrison, 1995), laid out in layers with different amylase and amylopectin content (Song and Jane, 2000; Svihus *et al.*, 2005). Barley, as well as wheat and rye, contain two types of starch granules — A (large, lenticular) (>10 μm) and B (small, round) (<10 μm) (Vasanthan and Bhatty, 1996). The starch granules are gradually developed over the grain maturation period. A-type granules constitute only about 10–15% in mature grain, but constitute up about 90% of the total weight of starch. A-type starch granules contain more amylose than in small B-type granules (Kang *et al*., 1985; Ao and Jane, 2007;). The number and ratio of A and B types of the starch granules are determined both by the genotype and environmental factors (Kang *et al*., 1985; Morrison *et al*., 1986; Li *et al*., 2001).

In contrast to non-ruminants, the saliva of ruminant animals does not contain the enzyme amylase, and therefore, the process of breaking down the starch is not started in the mouth. When grain reaches the rumen, reticulum and omasum, microbial enzymes break down the fibreous structures, starch and protein of grain before the feed passes on to abomasum and the small intestine, where it becomes in contact with amylase, protease and lipase (Huntington, 1997). As the first, second and third stomach is the main site of starch digestion, the starch digestion rate could be the main factor causing digestive disorders and affecting animal productivity. When grain is digested too quickly and thus preventing animals from fully benefiting from the energy contained in grain, barley is commonly referred to as the 'hot' feed (Bowman *et al*., 2001). In the case when starch digestion is excessively fast, the pH level declines resulting in slowing down of microbial digestion, reduction of feed intake and loss of the daily weight gain (Hogan and Flinn, 1999; Hunt, 1996). Bowman *et al.* (2001) and Svihus *et al.* (2005) indicate that proteins closer bound to starch granules, as observed in barley with higher hardness, slows down the digestion of starch in the animal stomach, thus transferring this process to the small intestines, which is a desirable property in feed barley. In barley genetic improvement programmes conducted in Canada and the USA, varieties with relatively low dry matter digestibility are selected ('slow DMD' barley) (Bowman *et al*., 2001).

Non-starch polysaccharides. Non-starch polysaccharides — (1→3) and (1→4) β-D-glucan (β-glucan) and arabino-(1→4) β-D-xylan (arabinoxylan) are mainly found in the cell wall of the aleurone layer and starch with 3–5 μm thickness (Bacic and Stone, 1981; Newman and Newman, 1992b). The barley starch cell wall contains 75% β-glucan, 20% arabinoxylan and 2% cellulose (Evers *et al*., 1999; Shewry and Morell, 2001). Varieties with high β-glucan content have a thicker cell wall (Oscarsson *et al*., 1997; Zheng *et al*., 2000). Content of β-glucan in the dry matter of barley usually varies from 2 to 7% (Oscarsson *et al*., 1997; Grausgruber *et al*., 2004). The traits of non-starch polysaccharides are important in relation to nutritional value of barley grain used as food (Fastnaught *et al*., 1996) and feed (Engstrom *et al*., 1992). The studies show that consumption of food with high β-glucan content decreases the cholesterol level and stabilises the blood glucose level, both for humans and animals (Klopfenstein, 1988; Newman *et al*., 1989). On the other hand, the use of high β-glucan content poultry feed may create problems (Newman and Newman, 1992a). It has been established that feeding poultry a diet with high barley content, β-glucan affects the poultry health and productivity by causing viscose-like faeces (McNab and Smithard, 1992). β-glucan, especially its soluble fraction, has a major impact on the viscosity of barley extract and therefore, this indicator has been widely studied both in relation to barley use in food (Andersson *et al*., 1999a) and feed (Campbell *et al*., 1989; Izidorczyk *et al*., 2000; Svihus and Gullord, 2002). R. Bhatty, a scientist from Canada, proposed extract viscosity measurement as a simple method to assess β-glucan content in in early hybrid stages of varieties suitable for feed (Bhatty, 1987). For genotypes with low and high β-glucan content in grain, a difference of the placement of β-glucan within the endosperm exists. Namely, for varieties with low β-glucan content, it is stored mainly in the aleurone layer, while for genotypes with high β-glucan content it is distributed evenly throughout the whole cell wall of the grain endosperm. Since this factor affects milling quality, it should be taken taken into consideration for barley which is used for food and for feed (Zheng *et al*., 2000).

To describe the digestibility of feed material, including barley, two indicators are often used: Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) — both reflecting the **fibre** contents in feed (Ositis, 1998). The above indicators are often listed in chemical composition tables of feed and area included in statistical calculations (Zhang *et al*., 1994). They are also used for assessment of germplasm (See Newman and Newman, 1992a). NDF comprises hemi-cellulose, cellulose, lignin, lignified nitrogen or unavailable protein, insoluble ash and silica. NDF limits the animal's ability to take in the dry matter, energy and feed. ADF or lingo-cellulose incorporates cellulose, lignin, lignified nitrogen and silica. The difference between NDF and ADF characterises the amount of hemi-cellulose, or cell sugar (Ositis, 1998). Both NDF and ADF are practically indigestible in the gastro-intestinal tract of humans and non-ruminant animals (Newman and Newman, 1992b). Among different genotypes of barley, NDF content varied from 12 to 20%, and that of ADF from 4 to 8% (Bhatty and Christison, 1975). A higher fibre content is associated with lower digestibility (Fairbairn *et al*., 1999). This relationship is valid for all groups of animals, especially species with a single stomach, i.e., pigs and poultry. Therefore, barley varieties with reduced fibre content have higher feed value for non-ruminants. A small amount of fibre in the diet is important for all domestic animals for transit of feed through the gastro-intestinal tract and promotion of excretion of toxic material (Newman and Newman, 1992a). Hunt (1996) points out that the consumption efficiency of the energy contained in barley is influenced by the digestibility indicator of the fibrous part of grain. It has been established that NDF and hull content in grain have a significant adverse impact on digestibility *in situ*. Varieties with lower dry matter digestibility are characterized also by lower hull digestibility. Thus, varieties with elevated fibre, ADF and NDF content in grain should be utilised for feeding ruminants, as this would slow down the dry matter digestibility in the stomach of the animal, eventually improving the efficiency of using the energy contained in starch (Hunt, 1996).

Nitrogen-containing substances or **proteins** in organic matter found in the dry matter of feed are of utmost importance (Osītis, 1998). The protein of barley, identical to that of other cereals, is an aggregate of 20 amino acids, the combinations of which determine three physiological functions of proteins in the system: metabolic, structural and back-up function (Newman and Newman, 1992b; Evers *et al.*, 1999). Protein makes up the second largest fraction of the grain endosperm. Dry matter of the barley grain consists of 8–20% crude protein (Evers *et al.*, 1999).

Protein can be divided into four groups, depending on their solubility in different solvents. Protein solubility fractions are named albumin, globulin, glutelin and hordein. The hordein fraction represents the major group of storage protein in the grain. Hordein can be classified into three groups of polypeptides called B, C, D hordeins based on their electrophoretic mobility (Evers *et al.*, 1999). The B and C fractions account for 70–80% and 10–12%, respectively, of the total hordein, while the D fractions are a minor component (about 5%). Each group of hordein is synthesised from a family of structural genes. The major B-hordein and C-hordein are encoded by the multigenic loci *Hor2* and *Hor1*, respectively, both located on the short arm of chromosome 5. D-hordein synthesis is encoded by the *Hor3* locus located on the long arm of chromosome 5 (Shewry and Halford, 2002). These different hordeins differ in molecular weight and amino acid composition. In barley, alcohols soluble protein, or prolamin, has poor nutritional quality, it is notably deficient in the essential amino acid lysine, and is responsible for poor quality of the whole grain when used as a diet for monogastric animals (Molina-Cano *et al.*, 2000). The ratio of B and C- hordein fractions influences grain hardness and extractivity (Peltonen *et al.*, 1994). Molina-Cano *et al.* (2000) suggested that both B-hordeins and β-glucan are relevant to water uptake. B and C-hordein have been shown to be associated also with milling energy, as an increase in C-hordein along with a decrease in β-glucan was related to a decrease in milling energy, a characteristic trait of grain hardness (Molina-Cano *et al.*, 1996).

Amino acids are divided into two large groups: essential and non-essential amino acids. Non-essential amino acids are synthesised by animals while essential amino acids need to be consumed with feed in order to ensure adequate metabolic processes (Degola and Belicka, 2005). Amino acids determine the biological value of protein. Of the 20 amino acids, eight are essential (valine, isoleucine, leucine, methionine, threonine, lysine, tripthophan, phenylalanine), eight are non-essential (asparagine, alanine, glutamine, glycine, proline, aspartic acid and glutamic acid) and four are partially essential (arginine, histidine, cysteine and tyrosine) (Newman and Newman, 1992b). The essential amino acids, apart from playing an indispensable role in protein synthesis, are of major importance also in metabolic processes and implementation of specific functions in non-ruminant domestic animals. Lysine has a special role in metabolism of the amino acids directly by participating in their syntheses; consequently, the amount of protein in the system is almost totally dependent on the content of lysine in the feed ration. When balancing the ration according to amino acid requirements, lysine is deemed the leading amino acid and is expressed as 100%. This is because lysine is almost totally used for formation of amino acids in animals while other amino acids, which are also needed in the pig feed, are not wholly used in the production of amino acids (Degola and Belicka, 2005). Therefore, regarding quality of barley protein, the strongest emphasis usually is placed on lysine (Osītis, 1998). A higher protein content in grain is associated with lower content of essential amino acids. This is due to the increase of hordein, a back-up protein containing a high percentage of glutamic acid, a nonessential amino acid, as well proline, but very little lysine (Newman and Newman, 1992b). A high content of glutamic acid and proline in protein of barley is not desirable, as these amino acids are practically unavailable to animals and cause environment pollution with nitrogen compounds (Lange *et al.*, 2006).

Protein and amino acids play also a role in physiological processes of ruminants. It is especially important for young animals receive high protein feed (Degola and Belicka, 2005). Nevertheless, ruminants can survive on a diet lacking high quality protein, as microbes in their gastro-intestinal tract are capable of synthesising 50% of both essential and non-essential amino acids. The nitrogen needed for the above synthesis is obtained by micro-organisms in the process of breaking down the nitrogen-containing fractions of the feed material (Osītis, 1998). Therefore, C. Newman and R. Newman (1992a) consider that barley varieties with elevated crude protein content in grain would be more appropriate for ruminant domestic animals. One of the factors determining the uptake of protein and amino acids in ruminants is rumen protein solubility. The protein fractions albumin and globulin have higher solubility than prolamine and gluteine. As barley mostly contains the prolamine fraction, the protein digestibility in rumen constitutes about 70%. Protein digestibility further affects starch digestibility (Barneveld, 1999). Bhatty *et al.* (1974) considers that 11% protein content in barley used for feed would be sufficient; breeding for low protein content is usually related to high starch content in grain and higher yield of grain.

There have been attempts to improve barley protein quality through manipulating genes of specific mutations. In 1967, a variety was established in the World Barley Collection of Plant Gene Resources with elevated lysine content in protein, named ‘Hiproly’ (carrier of gene *lys1*) (Munk *et al.*, 1970). Another gene (*lys3a*) was discovered by ‘Riso 1508’ (Doll, 1973). High lysine genotypes are distinguished by a higher lysine proportion in protein and their protein is better balanced. This is due to a lower proportion in protein of glutamic acid and proline, amino acids that are valueless for non-ruminants. Hordein fractions of high lysine genotypes characterised by a higher proportion of low molecular weight (B hordein) fractions were found to be rich in lysine and other essential amino acids (Klemsdal *et al.*, 1987).

Mutants high in lysine usually have reduced starch content (Helm *et al.*, 1974; Salomonsson *et al.*, 1980). In the study of Aman and Newman (1986), the starch content in high lysine genotypes varied from 25% for the line 'Riso 13' to 54% for the line 'Riso 56'. As lower average grain weight is inherent to this genotype, its hull content was by 2% higher (which relatively increased also the fibre content in grain) in comparison with that of conventional barley (Gabert *et al.*, 1996). Also, agronomic indicators, such as 1000 grain weight and grain productivity, are significantly lower in lines high in lysine, compared to thse for conventional barley (Eggum *et al.*, 1995).

A relevant quality indicator of feed barley is the **lipid or fat** content of grain. In cereals, the lipid content varies from 1% to 14% (Svihus *et al.*, 2005), while barley usually contain 2–3% crude fat (Newman and Newman, 1989). For barley, approximately 30% of fat is concentrated inside the germ (Andersson *et al.*, 1999b). Part of the fat is found on the surface of starch granules (Welch, 1978). Fat is an important source of energy for animals, and can ensure 2.25 times higher energy per unit of weight than carbohydrates. Fat is also a significant body heat regulator. Elevated fat content of barley grain facilitates the milling process (Newmans and Newman, 1992a). Fat has high importance in relation to improvement of barley feed value and an increase of fat content can be achieved through genetic improvement (Welch, 1978). In his study, among 86 barley varieties, the crude fat content varied between 1.9–4.1%.

Barley grain has low low **minerals** content, which does not fully meet the animal's needs (Newman and Newman, 1992a). Minerals, mainly P, Ca, Mg and K, are mostly found in the aleurone layer of grain (Stewart *et al.*, 1988). The amount of minerals in barley grain is small and reaches the concentration required to ensure the physiological processes over the germination period of grain (Evers *et al.*, 1999). Among the minerals, closer attention is paid to phosphorus, as its supplementation to feed significantly increases feed costs. Barley usually contains about 0.34–0.45% phosphorus. In barley grain, about 70% of the phosphorous content is found in the form of phytic acid or phytates (mean 0.25–0.30% in dry matter of grain), which is fully consumed by ruminants but unavailable for non-ruminants, consequently polluting the environment with phosphorus compounds and reducing feed efficiency (Linares *et al.*, 2007; Raboy *et al.*, 2000). Phytic acid slows down the exchange of other important trace elements: zinc, magnesium and calcium, which can cause zinc deficiency problems for non-ruminants (Selle *et al.*, 2000; Veum *et al.*, 2002). As phytic acid is known to form complex compounds with proteins, the digestibility of protein and amino acids is reduced under its influence (Kies *et al.*, 2001). Special breeding programmes have been targeted to increase the available phosphorous in grain (Poulsen *et al.*, 2001; Rosnagel, 2000). Usually, however, by reduction of the phytic acid level, the total phosphorus content in grain is also diminished (Newman and Newman, 1992b). For barley genotypes created by the mutagenesis, the proportion of inorganic phosphorus is increased, but the total phosphorous content remains unchanged, as the ratio of phytic acid constitutes only 13–43% of the total phosphorus in grain (or 0.09–0.14% in dry matter) (Bowen *et al.*, 2006; Poulsen *et al.*, 2001). A low phytate level in grain is critical also for malting barley, since an significant negative correlation has been established between the phytate content and the extract outcome, and between phytate content and the content of total protein in grain (Dai *et al.*, 2007). For food barley, a low phytate level is also advisable, as it limits the availability of minerals in the same way as in feed. Some studies have confirmed the beneficial role of phytates in cancer prevention (Selle *et al.*, 2000). Calcium constitutes only about 0.05% of the dry matter of barley grain. It is the most required mineral both in animals, including poultry, and can be easily added to the ration at sufficiently low cost (Newman and Newman, 1989).

Barley contains **Vitamin E**, one of the most significant natural anti-oxidants. The amount of the Vitamin E in grain is genetically pre-disposed and varies from one variety to another from 16.2 to 23.8 mg kg^{-1} (Pryma *et al.*, 2007). Barley is a valuable source of B vitamin, with an exception of B12 (Newman and Newman, 1992b).

On the basis of information collected from scientific literature, a profile of a high quality feed barley variety for different groups of animals is presented in Table 1.

AGRONOMIC TRAITS IMPORTANT FOR FEED BARLEY

For cost-effectiveness of feed barley cultivation, it is essential for the variety to have a sufficiently high yield potential. Therefore, breeders carrying out genetic improvement of feed barley should concurrently keep in mind also the balanced position of quantitative and qualitative traits of grain. In the same way, account should be taken of meteorological conditions, which can adversely impact feed grain quality over the grain maturation period. Warm and damp weather after the blooming phase, recently observed in Latvia, promotes infection of barley with diseases caused by *Fusarium* spp., shedding mycotoxins, such as deoxinovalenol (DON). Such grain is not fit for feeding of any animals, and piglets are especially susceptible to it. Therefore, genetic resistance of a feed barley variety against fusariosis is critical. As mycotxins are mostly contained in hull of barley grain, hull-less barley has significantly lower ($P < 0.05$) mycotoxin content than hulled barley (Legzdina and Buerstmayr, 2004). Near infrared spectroscopy (NIRS) technologies can be used for fast evaluation of germplasm for presence of mycotoxins in grain (Arganosa *et al.*, 2003).

SUMMARY

The reviewed literature indicates that the feed quality of barley is influenced both by physical grain quality indicators (colour, grain weight and size, hull content, 1000 grain weight, volume weight and grain hardness) and chemical composition (protein, carbohydrates, non-starch polysaccharides, amino acids, fibre, protein, fat, minerals and vita-

Table 1

MODEL PROFILE OF HIGH QUALITY SPRING BARLEY VARIETY FOR USE IN FEED FOR ANIMALS OF DIFFERENT GROUPS CONSTRUCTED ON THE BASIS OF GRAIN QUALITY INDICATORS

Trait	Ruminants	Pigs	Poultry
1000 grain weight	high	high	high
Volume weight	high	high	high
Starch content	high (starch high in amylose)	high (waxy endosperm, high ration of B granules)	high (waxy endosperm, high ratio of B granules)
Crude protein content	average to high, low hordein proportion in protein	average	average
β-glucan	high	average (low proportion of soluble fraction)	average (low proportion of soluble fraction)
Amino acid content	composition is not important	high proportion of the essential and low proportion of non-essential amino acids in protein	high proportion of the essential and low proportion of non-essential amino acids in protein
Crude ash content	high	high	high
Hull content	low to average	low (hull-less barley: high value feed)	low (hull-less barley: high value feed)
Fibre content	low to average	low	low
Grain hardness	hard endosperm of grain	averagely soft endosperm of grain	averagely soft endosperm of grain
Content of minerals and vitamins	high	high content of organic or available phosphorus (low content of phytic acid)	high content of available phosphorus (low content of phytic acid)

mins). Breeders working towards the genetic improvement of feed barley need to think concurrently about balancing the quantitative and qualitative indicators.

An important role in success of the feed barley breeding outcome is played by access to high genetic diversity of quality traits on the part of the breeder. Experience has shown that efficient building on genetic diversity can produce a variety with physical and chemical indicators of grain quality that ensures agricultural animals with maximum energy value while reducing the feed costs. Grain quality for different types of barley, i.e., two-row, six-row, hulled and hull-less genotypes differs. The specific chemical composition (high β-glucan and crude fat content) is characteristic of genotypes with waxy endosperm, while genotypes high in lysine have an elevated ratio of essential amino acids in protein.

From a commercial point of view, the productivity and disease resistance will continue to be important descriptors of a feed barley variety. Likewise important for high quality feed barley are such indicators such as purity, grain colour, and moisture content which can affect grain storage, digestibility and processing. However, under intensive production systems, the users of feed grain that consider the feeding rations and calculate the feed costs will be more interested to take into account indicatorsof feeding value of grain and its quality for each species of the agricultural animals.

REFERENCES

Aman, P., Hesselman, K., Tilly, A.C. (1985). The variation in chemical composition of Swedish barleys. *J. Cereal Sci.*, **3**, 73–77.

Aman, P., Newman, C.W. (1986). Chemical composition of some different types of barley grown in Montana USA. *J. Cereal Sci.*, **4**, 133–141.

Andersson, A.A.M., Andersson, R., Autio, K., Aman, P. (1999a). Chemical composition and microstructure of two naked waxy barleys. *J. Cereal Sci.*, **30**, 183–191.

Andersson, A.A.M., Elferson, C., Andersson, R., Regner, S., Aman, P. (1999b). Chemical and physical characteristics of different barley samples. *J. Sci. Food Agr.*, **79**, 979–986.

Anonymous (2012). Barley Export and Market Forecasts, 2012. See: http://www.reportlinker.com/report/search/theme/barley_export

Ao, Z., Jane, J. (2007). Characterisation and modeling of the A- and B-granule starches of wheat, triticale and barley. *Carbonhydrate Polymers*, **67**, 46–55.

Arganosa, G.C., Rossnagel, B.G., Legge B.G., Zatorski T., Tucker J. (2003). Prediction of Deoxynivalenol (DON) in Feed Barley using Near-Infrared Spectroscopy. In: *3rd Canadian Barley Symposium* (19–20 June 2003), pp. 96. Red Deer, Alberta.

Bacic, A., Stone, B.A. (1981). Chemistry and organization of aleirone cell wall components from wheat and barley. *Austral. J. Plant Physiol.*, **8**, 475–495.

Barneveld, S.L. (1999). Chemical and physical characteristics of grains related to variability in energy and amino acid availability in ruminants: A review. *Austral. J. Agr. Res.*, **50**, 651–666.

Beecher, B., Bowman, J., Martin, J.M., Bettge, A.D., Morris, C.F., Blake, T.K., Giroux, M.J. (2002). Hordoindolines are associated with a major endosperm-texture QTL in Barley (*Hordeum vulgare* L.). *Genome*, **45**, 584–591.

Bell, J.M., Shires, A., Keith, M.O. (1983). Effect of hull and protein content of barley on protein and energy digestibility and feeding value of pigs. *Canad. J. Animal Sci.*, **63**, 201.

Bhatty, R.S., Christison, G.I., Sosulski, F.W., Harwey, B.L., Hughes, G.R., Berdahl, J.D. (1974). Relationships various physical and chemical characters to digestable energy of wheat and barley cultivars. *Can. J. Animal Sci.*, **54**, 419–427.

Bhatty, R.S., Christison, G.I. (1975). Chemical composition and digestable energy of barley. *Can. J. Animal Sci.*, **55**, 759–764.

Bhatty, R.S. (1986). The potential of hull-less barley-a review. *Cereal Chem.*, **63**, 97 – 103.

Bhatty, R.S. (1987). Relationship between acid extract viscosity and total soluble and insoluble β-glucan content of hulled and hulless barley. *Can. J. Plant Sci.*, **67**, 997–1008.

Bowen, D.E. Guttieri, M.J., Peterson, K., Peterson, K., Raboy, V., Souza, E.J. (2006). Phosphorus fractions in developing seeds of four low phytate barley (*Hordeum vulgare* L.) genotypes. *Crop Sci.*, **46**, 2468–2473.

Bowman, J.G.P., Blake, T.K., Surber, L.M.M., Habernicht, D.K., Bockelman, H. (2001). Feed-quality variation in barley core collection of the USDA National small grain collection. *Crop Sci.*, **41**, 863–870.

Camm, J.P., Ellis, R.P., Morrison, W.R. (2005). Milling energy. An investigation into the biochemical basis of hardness in cereals. *Aspects Appl. Biol.*, **25**, 121–131.

Campbell, G.L., Rossnagel, B.G., Classen, H.L., Thacker, P.A. (1989). Genotypic and environmental differences in extract viscosity of barley and their relationship to its nutritive value for broiler chickes. *Animal Feed Sci. Technol.*, **26**, 221–230.

Christison, G.I., Bell, J.M. (1975). An assesment of bulk weight and other simple criteria for predicting the digestable energy values of feed grains. *Can. J. Plant Sci.*, **55**, 515–528.

Dai, F., Wang, J., Zhang, S., Xu, Z., Zhang, G. (2007). Genotypic and environmental variation in phytic acid content and its relation to protein content and malt quality in barley. *Food Chem.*, **105**, 606–611.

Darlington, H.F., Tesci, L., Harris, N., Griggs, D.L., Cantrell, I.C., Shewry, P.R. (2000). Starch granule associated proteins in barley and wheat. *J. Cereal Sci.,* **32**, 21–29.

Darroch, C.S., Aherne, F.X., Helm, J., Sauer, W.C., Jaikaran, S. (1996). Effect of dietary level of barley hulls and fibre type on protein and energy digestibilities of Condor hulless barley in growing swine. *Animal Feed Sci. Technol*., **61**, 173–182.

Degola, L. Belicka, I. (2005). Hulless-barley for nutrition of high breeding value pig. In: *Proceedings of XI Baltic Animal Breeding and Genetics Conference*, May 2005, Palanga, Lithuania, pp. 202–206.

Doll, H. (1973). Inheritance of high lysin character of a barley mutant. *Hereditas*, **74**, 293–294.

Edney, M.J. (1996). Barley. In: *Cereal Grain Quality* (pp. 113–146). Henry, R.J., Kettlewell, P.S. (eds.). Cambridge: Chapman and Hall, The University Press.

Eggum, B.O., Braunsgaard, G., Jensen, J. (1995). The nutritive value of new high-lysine barley mutants. *J. Cereal Sci.,* **22**, 171–176.

Elfverson, C., Andersson, A.A., Aman, P., Regner, S. (1999). Chemical composition of barley cultivars fractionated by weighing, pneumatic classification, sieving, and sorting on a specific gravity tabele. *Cereal Chem.,* **76**(3), 434–438.

Engstrom, D.F., Mathison, G.W., Goonewardene, L.A. (1992). Effect of beta-glucan, starch, and fibre content and steam vs. dry rolling of barley grain on its degradability and utilisation by steers. *Animal Feed Sci. Technol.*, **37**, 33–46.

Evers, A.D., Blakeney, A.B., Brien, L.O. (1999). Cereal structure and composition. *Austral. J. Agr. Res.*, **50**, 629–650.

Fairbairn, S.L., Patience, J.F., Classen, H.L., Zijlstra, R.T. (1999). The energy content of barley fed to growing pigs: Charcterizing the nature of its variability and developing prediction equitions for its estimation. *J. Animal Sci.,* **77**, 1502–1512.

Fastnaught, C.F., Berglund, P.T., Holm, E.T., Fox, G.J. (1996). Genetic and environmental variation in β-glucan content and quality parameters of barley for food. *Crop Sci.,* **36**, 941–946.

Fox, G.P., Kelly A., Poulsen D., Inkerman A., Henry R. (2006). Selecting for increased barley grain size. *J. Cereal Sci*., **43**, 198–208.

Fox, G.P., Nguyen, L., Bowman, J., Poulsen, D., Inkerman, A., Henry, R. (2007). Relationships between hardness genes and quality in barley (*Hordeum vulgare* L.). *J. Inst. Brew*., **113** (1), 87–95.

Fregeau-Reid, J., Thin-Meiw, C., Ho, K., Martin, R.A., Konishi, T. (2001). Comparison of two-row and six-row barley for chemical composition using doubled-haploid lines. *Crop Sci*., **41**, 1737–1743.

Gabert, V.M., Jorgensen, H., Brunsgaard, G., Eggum, B.O., Jensen, J. (1996). The nutritional value of new high-lysine barley varieties determined with rat and young pigs. *Can. J. Animal Sci*., **76**, 443–450.

Gaines, C.S., Finney, P.F., Fleege, L.M., Andrews, L.C. (1996). Predicting a hardness measurements using the Single Kernel Characterisation System. *Cereal Chem.*, **73**, 278–283.

Grausgruber, H., Schoenlechner, R., Zahlner, V., Berghofer, E., Ruckenbauer, P. (2004). Beta-glucan content of old and modern spring barleys, In: *9th International Barley Genetic Symposium, Brno, Czech Republic, 20–26 June* (pp. 442–448). Brno.

Greenwell, P., Schofield, J.D. (1986). A starch granule protein associated with endosperm softness in wheat. *Cereal Chem.*, **63**, 379–380.

Helm, J.H., Metzer, R.J., Kronstad, W.E. (1974). Inheritance of high lysine in Hiproly barley and its association with the Hiproly endosperm gene. *Crop Sci.*, **14**, 637–640.

Henry, R.J., Cowe, I. (1990). Factors influencing the hardness (milling energy) and malting quality of barley. *J. Inst. Brew.*, **96**, 135–136.

Hogan J.P., Flinn P.C. (1999). An assessment by in vivo methods of grain quality for ruminants. *Austral. J. Agr. Res.*, **50**, 843–854.

Holopainen, U.P., Wilhelmson, A., Salmenkallio-Marttila, M., Peltonen-Sainio, P., Reinikainen, P., Kotaviita, E., Simolin, H., Home, S. (2005). Endosperm effects the malting quality of barley (*Hordeum vulgare* L.). *J. Agr. Food Chem.*, **53**, 7279–7287.

Hunt, C.W. (1996). Factors affecting the feeding quality of barley for ruminats. *Animal Feed Sci. Technol.*, **62**, 37–48.

Huntington, G.B. (1997). Starch utilization by ruminats: From basics to the bunk. *J. Animal Sci.*, **75**, 852–867.

Izydorczyk, M.S., Storslay, J., Labossiere, D., MacGregor, A.W., Rossnagel, B.G. (2000). Variation in total and solube β-glucan content in hulless barley: Effects of thermal, physical and enzimatic treatments. *J. Agr. Food Chem*., **48**, 982–989.

Jagtab, S.S., Beardsley, A., Forrest, J., Ellis (1993). Protein composition and grain quality in barley. *Aspects Appl. Biol.*, **36**, 51–59.

Kang, M.Y., Sugimoto, Y., Kato, I., Sakamoto, S., Fuwa, H. (1985). Some properties of large and small starch granules of barley (*Hordeum vulgare* L.) endosperm. *Agr. Biol. Chem*., **49**, 1291–1297.

Kies, A.K., Van Hemert, K.H.F., Sauer, W.C. (2001). Effect of phytase on protein and amino acid digestibility and energy utilization. *World's Poultry Sci. J.*, **57**, 109–126.

Klemsdal, S.S., Olsen, O.A., Rorvik, K.A. (1987). The barley high lysine genes of mutants 1508 and 527 alter hordein polypeptide composition quantitatively, but not qualitatively. H*ereditas*, **107**(1), 107–114.

Klopfenstein, C.F. (1988). The role of cereal beta-glucans in nutrition and health. *Cereal Foods World*, **33**, 865–869.

Lange, M., Vincze, E., Wieser, E., Holm, H. (2006). Developing a feed barley with improved amino acid composition to meet environmental and nutritional demands. In: *Proceedings of Eucarpia Conference. Cereal Science and technology for feeding ten billion people: Genomics era and beyond 13–17 November 2006, Lleida, Spain* (pp. 305–308).

Legzdina, L., Buerstmayr, H. (2004). Comparison of infection with Fusarium head blight and acumulation of micotoxins in grain of hulless and covered barley. *J. Cereal Sci.,* **40**(1), 61–67.

Li, J.H., Vasanthan, T., Rossnagel, B., Hoover, R. (2001). Starch from hull-less barley: I Granule morphology, composition and amylopectin structure. *Food Chem.*, **74**, 395–405.

Linares, L.B., Broomhead, J.N., Guaiume, E.A., Ledoux, D.R., T. L. Veum, T.L., Raboy, V. (2007). Effects of low phytate barley (*Hordeum vulgare* L.) on zinc utilization in young broiler chicks. *Poultry Sci.*, **86**, 299–308.

Manner, D.J. (1985). Some aspects of the structure of starch. *Cereal Food World*, **30**, 461–467.

Mauro, D.J. (1996). An update on Starch. *Cereal Food World*, **41**, 776–780.

McNab, J.M., Smithard, R.R. (1992). Barley β-glucan: An antinutritional factor in poultry feeding. *Nutr. Res. Rev.*, **5**, 45–60.

Molina-Cano, J.L., Voltas, J., Irta, U. de L. (1996). β-glucan and hordein contents of developing grain in Spain and Scotland. In**:** *Proceedings of V International Oat conference & VII Barley genetic Symposium*, 30 July – 6 August 1993, Saskatoon (pp. 132–133). Saskatoon.

Molina-Cano, J.K., Swanston, J.S., Ulrich, S.E. (2000). Genetic and environmental effects on malting and feed quality of barley: A dynamic field of study. In: *8th International Barley Genetics Symposium, Barley Genetics VIII. 22–27 October 2000, Adelaide (*pp. 127–134). Adelaide.

Morrison, W.R., Scott, D.C., Karkalas, J. (1986). Variation in the composition and physical properties of barley starch. *Starke*, **38**(11), 374–379.

Morrison, W.R. (1995). Starch lipids and how they relate to starch granules structure and functionality. *Cereal Food World*, **40**, 437–446.

Munk, L., Karlson, K.E., Hagberg, A., Eggum, B.O. (1970). Gene for improved nutritional value in barley seed protein. *Science*, **168**, 985–987.

Munk, L. (1981). Barley for food, feed and industry. In: *Cereals. A Renewable Resource, Theory and Practice* (pp. 427–459). Pomeranz, Y., Munk, L. (eds.). St. Paul, MN: American Association of Cereal Chemists.

Newman, R.K., Newman, C.W., Graham, H. (1989). The hypocholesterolemic function of barley β-glukans. *Cereal Food World*. **34**, 883–886.

Newman, C.W., Newman, R.K. (1989). Nutritional aspects of barley as a livestock feed. In: *Proceedings of the Prairie Barley Symposium. 20–22 March 1989 Saskatoon* (pp. 99–107). Saskatoon.

Newman, C.W., Newman, R.K. (1992a). Characteristics of the ideal barley for feed, Barley research reviews 1986–91. In: *Barley Genetics VI Session and Workshops Summaries*, II (pp. 925–939). Munksgaard International Publishers.

Newman, C.W., Newman, R.K. (1992b). Nutritional aspects of barley seed structure and composition. In: *Barley: Genetics, Biochemistry, Molecular Biology and Biotechnology* (pp. 351–368). Shewry, P.R. (ed.). CAB International.

Olkku, J., Kotaviita, E., Salmenkallio-Martilla, M., Sweins, H., Holm, S. (2005). Connection between structure and quality of barley husk. *J. Amer. Soc. Brew. Chem.,* **63**, 17–22.

Oscarsson, M., Parkkoen, T., Auto, K., Aman, P. (1997). Composition and microstructure of normal, waxy and high-amylose barley samples. *J. Cereal Sci.*, **26**, 259–264.

Osītis U. (1998). *Barības līdzeklu novertēšana atgremotāju ēdināšanā metodiskais materiāls* [Evalution of feeding materials for ruminants]. Jelgava, LLU. 48 lpp. (in Latvian).

Pasarella, V.S., Savin, R., Slafer, G.A. (2005). Breeding effects on sensitivity barley grain weight and quality to events of high temeprature during grain filling. *Euphytica*, **141**, 41–48.

Peltonen, J., Rita, H., Aikasalo, R., Home, S. (1994). Hordein and malting quality in northen barleys. *Hereditas*, **120**, 231–239.

Poulsen, H.D., Johansen, K.S., Hatzack, F., Boisen, S., Rasmussen, S.K. (2001). Nutritional value of low-phytate barley evaluated in rats. *Acta Agriculturae Scandinavica*, **51**(1), 53–58.

Pryma, J., Ehrenbergerova, J., Belcrediova, N., Vaculova, K. (2007). Tocol content in barley. *Acta Chim. Slovenia,* **54**, 102–105.

Raboy, V., Cook, A., Wesenberg, D., Rossnagel, G. (2000). Low phytate barleys. In: *Proceedings of 8th Intrenational Barley Genetic Symposium. 22–27 October 2000, Adelaide, Australia* (pp. 147–153). Adelaide.

Rodomiro, O., Nurminiemi, M., Madsen, S., Rognli, O.A., Bjornstad, A. (2002). Genetic gains of Nordic spring barley breeding over sixty years. *Euphytica*, **126**, 283–289.

Rossnagel B.G. (2000) Hulless barley — Western Canada corn. *Proceedings of the 8th International Barley Genetics Symposium*, Vol. 1 (pp. 135–142). Adelaide.

Salomonsson, A.C., Theander, O., Aman, P. (1980) Composition of normal and high-lysine barleys. *Swedish J. Agr. Res.*, **10**, 11– 16.

Selle, P.H., Ravindran, V., Caldwell, R.A., Bryden, W.L. (2000). Phytate and phytase: Consequences for protein utilization. *Nutr. Res. Rev.*, **13**, 255–278.

Shewry, P.R., Morell, M. (2001). Manipulating cereal endosperm structure, development and composition to improve end-use properties. *Adv. Bot. Res.*, **34**,165–234.

Shewry, P.R., Halford, N.G. (2002). Cereal seed storage proteins: Structures, properties and role in grain utilization. *J. Exper. Bot.,* **53**. 947–958.

Shirley, B.W. (1998). Flavonoids in seeds and grains: Physiological function, agronomic importance and the genetics of biosynthesis. *Seed Sci. Res.*, **8**, 415–422.

Song, Y., Jane, J. (2000). Characterisation of barley starches of waxy, normal and high amilose varieties. *Carbohydr. Polym.*, **41**, 365–377.

Stewart, A., Nield, H., Lott, J.N.A. (1988). An investigation of the mineral content of barley grains and seedlings. *Plant Physiol.*, **89**, 93–97.

Svihus, B., Gullord, M. (2002). Effect of chemical content and physical characteristics on nutritional value of wheat, barley and oat for poultry. *Animal Feed Sci. Technol.,* **102** (1–4), 71–92.

Svihus, B., Uhlen, A.K., Harstad, O.M. (2005). Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: A review. *Animal Feed Sci. Technol.,* **122**, 303–320.

Swantston, J.S. (1997). Waxy starch barley genotypes with reduced β-glucan content. *Cereal Chem.*, **74**, 452–455.

Turuspekov, Y., Beecher, B., Darlington, Y., Bowman, J., Blake, T.K., Giroux, M.J. (2008). Hardness locus sequence variation and endosperm texture in spring Barley. *Crop Sci.*, **48**, 1007–1019.

Ullrich, S.E., Han, F., Froseth, J.A., Jones, B.L., Newman, C.W., Wesenberg, D.M. (1996). Mapping of loci affect carbonhydrate content in barley grain. In: *Proceedings of V International Oat Conference & VII Barley Genetic Symposium, Saskatoon, 30 July – 6 August 1993* (pp. 141–143). Saskatoon.

Vasanthan, T., Bhatty, R.S. (1996). Physicochemical prpoperties of small- and large-granule starches of waxy, regular and high amilose barleys. *Cereal Chem*, **73**, 199–207.

Veum, T.L., Ledoux, D.R., Bollinger, D.W., Raboi, V., Cook, A. (2002). Low phytic acid barley improves calcium and phosphorus utilisation and growth performance in growing pigs. *J. Animal Sci.*, **80**, 2663–2670.

Washington, J.M., Box, A., Karakousis, A., Barr, A.R. (2000). Developing Waxy Barley cultivars for food, feed and malt. In: *Proceedings of the 8th International Barley Genetic Symposium*, *Barley Genetics, VIII, Vol. II* (pp. 303–306).

Welch, R.W. (1978). Genotypic variation of oil and protein barley grain. *J. Sci.Food Agr.*, **29**, 953–958.

Wrigley, C.W. (1999). Potential methodologies and strategies for a rapid assessment of feed grain quality. *Austral. J. Agr. Res.*, **50**, 789–805.

Xue, Q.L., Newman, C.W., Graham, H. (1997). Influence of the hulless, waxy starch and short-awn genes on the composition of barleys. *J. Cereal Sci.*, **26**, 251–257.

Zhang, W.J., Campbell, L.D., Stothers, S.C. (1994). An investigation of the feasibility of predicting nitrogen corrected true metabolizable energy (TMEn) content in barley from chemical composition and physical characteristics. *Can. J. Animal Sci.*, **74**, 355–359.

Zheng, G.H., Rossnagel, B.G., Tyler, R.T., Bhatty, R.S. (2000). Distribution of β-glucan in the grain of hull-less barley. *Cereal Chem.*, **77**, 140–144.

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LOPBARĪBAS MIEŽU GRAUDU KVALITĀTES RĀDĪTĀJU RAKSTUROJUMS

Mieži (*Hordeum vulgare* L.) ir nozīmīga graudaugu suga izmantošanai lopbarībā, īpaši ziemeļu apgabalos, arī Lavijā. Ir grūti definēt ideālus lopbarības miežus, jo dažādām mājdzīvnieku sugām un pat vienas sugas ietvaros vecuma grupām ir ļoti atšķirīgas prasības. Tāpēc līdz šim lopbarības miežu selekcija ir attīstījusies ļoti lēni un veidojusies uz agronomisko un alus miežu kvalitatīvo rādītāju bāzes. Miežu šķirņu selekcijas process noteiktam graudu izmantošanas virzienam ir saistīts ar izlasi pēc dažādiem rādītājiem, jo graudu kvalitāte ir kompleksa kvantitatīva pazīme, kura atkarīga gan no graudu fizikālajiem parametriem, gan no ķīmiskā sastāva. Rakstā apkopotā informācija liecina, ka miežu lopbarības kvalitāti ietekmē gan fizikālie graudu kvalitātes rādītāji (graudu krāsa, plēkšņu saturs, graudu masa un izmēri, 1000 graudu masa, tilpummasa, graudu cietība), gan graudu ķīmiskais sastāvs (ogļhidrāti, ne-cietes polisaharīdi, proteīns, aminoskābes, kokšķiedra, tauki, minerālvielas un vitamīni). Pamatojoties uz zinātniskajā literatūrā iegūto informāciju, izveidoti augstvērtīgas lopbarības miežu šķirnes raksturojumi izmantošanai dažādām mājdzīvnieku grupām.