The Potential of Hull-less Barley—A Review

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ABSTRACT

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The potential of hull-less barley for use as feed and food is discussed and pertinent literature reviewed. Hull-less barley is nutritionally superior to hulled barley for swine and poultry. Only broiler chicks are unable to utilize hull-less barley like hulled barley, mainly because of β-D-glucans; however, their deleterious effects are completely removed by gamma irradiation or treatment of the grain with exogenous preparations containing β-D-glucanases. Hull-less barley can be pearled, malted, or milled to flour (about 72% yield) with conventional equipment used for milling soft wheat. The malt can be used directly, like wheat malt, in many food preparations. Barley flour has many potential uses in bread and nonbread bakery products.

Key words: Feed Quality, Food potential

Hull-less or naked barley has been in existence as long as, if not longer, than its close relative hulled or covered barley. Its nutritional significance, particularly for monogastric animals (swine) and poultry, has been realized only recently, however. Very little, if any, hull-less barley is used in human foods in western countries. Even in Asia, where pearled barley is an important dietary cereal, it is gradually being replaced by rice and wheat as economic conditions of the people improve. Hull-less barley is now primarily used as food in primitive mountainous regions of the world (Kent 1975).

Barley is an underutilized cereal in human foods. In Canada, barley is grown mainly for malt. The malting industry uses only about 10% of the total Canadian production of barley; the rest (85%) is used for animal feed (Rossnagel et al 1981). In the United States, per capita barley consumption for food other than malt was reported at only 0.5 kg compared to 50 kg for wheat, 3.5 kg for rice, and 0.5 kg for rye (Pomeranz 1973). This pattern of consumption has probably changed little in the last decade. At the turn of the century, barley was a major dietary source in Denmark, where it has now been completely replaced by wheat (Munck 1981).

Hull-less barley has potential for use in human foods. Unlike hulled barley, which contains 5–6% crude fiber (Bhatty et al 1974) that is a major deterrent to its use in foods, hull-less barley contains the same level of crude fiber as wheat and corn. The potential of hull-less barley needs to be developed. Like hulled barley, it is a highly adaptable and economic crop. It can be grown under a wide range of environments including desert oases of North Africa, the submontane regions and plains of the Indian subcontinent, and even in some portions of the Arctic. Over 150 cultivars of hulled barley are available for growing in North America alone (Reid and Wiebe 1979).

Hull-less Character of Barley

The family Gramineae (subfamily Festucoideae; tribe Hordeae) to which hull-less barley belongs includes wheat, rye, corn, millet, and sorghum, which are naked or hull-less, whereas barley, rice, and oats may be covered or hulled. More recently, hull-less cultivars of barley and oats have been developed. The hull or hull-less characteristic is established during development and maturation of grain. A mature barley plant has a head or spike to which are attached a number of spikelets. Each spikelet has two flowering glumes, lemma and palea, which may be awned or awnless. These glumes completely enclose the developing seed, or caryopsis. In hulled barley the flowering glumes are fused and strongly adhere to the seed with a cementing substance secreted by the caryopsis within 10 days before flowering (Harlan 1920, Reid and Wiebe 1979). A more recent study (Gaines et al 1985) showed that the cementing substance is produced by the undifferentiated pericarp-epidermis only two days after flowering. The chemical composition of the cementing substance remains unknown. In hull-less barley, fusion of the flowering glumes does not occur, and the unattached, loose husk is visibly separated from the grain during threshing. Genetic studies have shown that hull-less character in barley is controlled by a single recessive gene. Near-isogenic lines of hull-less barley have been produced by backcrossing hull-less with hulled cultivars for seven generations (Eslick 1979).

Hull-less barley is visibly distinguishable from hulled barley, and such a distinction may be used to classify malting and nonmalting barleys. Either form may be two-rowed, six-rowed, blue, yellow, purple, or may even have dark grain color due to melanin-like pigments in the pericarp. The purple or blue colors are caused by anthocyanin pigments, which appear red or purple in the pericarp and blue in the aleurone (Pomeranz 1973). The change in color is caused by the pH of the tissue. The aleurone tissue is alkaline, whereas the pericarp is acidic (Reid and Wiebe 1979). Hull-less barley has exposed embryo, which may be liable to damage during threshing. Rossnagel et al (1981), however, reported little damage to embryo on threshing, as germination of hulled and hull-less genotypes grown at several locations across Canada was similar. A precautionary increase in seed rate (10–20%) may easily compensate for any reduction in germination of hull-less barley due to embryo damage. Hull-less barley, on the average of data from 93 station years, yielded 88% of hulled barley (Rossnagel et al 1981). A similar yield of hull-less barley grown at 149 locations in the United States has been reported (Eslick 1979). The present yield differential between these forms will gradually narrow and may even disappear as selection and improvement of hull-less barley germ plasm continues.

The hull constitutes 10–13% of the dry weight of barley grain (Bhatty et al 1975). Hull content can be easily determined either by mechanical dehulling with an oat dehuller or a barley pearler. It may also be determined chemically for small samples by boiling barley in 50% sulfuric acid (Essery et al 1956) or alkaline sodium hypochlorite (Whitmore 1960). Barley hull consists mainly of cellulose, hemicellulose, lignin, and a small quantity of protein (Palmer and Bathgate 1976). Table I shows that hull is the major contributor to crude fiber in barley. Removal of hull reduces the crude fiber content of barley (hull-less) to that of corn and wheat. Hull-less barley has higher protein content than hulled barley and corn (Bhatty and Rossnagel 1981). The essential amino acid composition of near-isogenic lines of these barleys is almost identical (Table II). Because of the crude fiber content, the digestible energy (DE) of hulled barley is lower than that of corn for various classes of livestock (Table III). Thus, hull exerts a deleterious effect on the DE of barley, either by acting as a diluent of available nutrients or by physically or chemically inhibiting nutrient digestion and absorption (Larson and Oldfield 1961).

Feed Versus Malting Barley

The primary function of feed barley is to provide DE or metabolizable energy (ME) for growth and development of the

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TABLE I
Average Proximate Composition of Hulled and Hull-less Barley and Corn[a]

Component (%)	Hulled Barley	Hull-less Barley	Corn
Dry matter	86.5	86.5	86.5
Protein (N × 6.25)	10.5	13.5	9.7
Ether extract	2.2	2.0	3.8
Fiber	4.0	1.4	1.8
Ash	2.2	1.5	1.2
Nitrogen-free extract	67.6	68.2	70.0

[a] From Bhatty and Rossnagel (1981).

TABLE II
Essential Amino Acid Composition of Two- and Six-Rowed Hulled and Hull-less Near Isogenic Lines of Barley (g/100 g dry matter)[a]

	Two-Rowed		Six-Rowed	
Amino Acid	Hulled (TR203)	Hull-less (6965-4-L-b)	Hulled (Conquest)	Hull-less (74-365)
Arginine	0.75	0.69	0.67	0.72
Cystine	0.35	0.34	0.31	0.36
Histidine	0.27	0.29	0.27	0.40
Isoleucine	0.57	0.51	0.50	0.54
Leucine	1.15	1.15	1.06	1.16
Lysine	0.39	0.41	0.38	0.41
Methionine	0.40	0.38	0.37	0.41
Phenylalanine	0.85	0.84	0.80	0.89
Threonine	0.59	0.52	0.53	0.59
Tyrosine	0.56	0.55	0.51	0.55
Valine	0.78	0.74	0.71	0.77
% Protein (N × 6.25)	16.5	15.6	14.9	16.4

[a] From Bhatty et al (1979); single determination.

TABLE III
Digestible Energy of Hulled Barley and Corn for Various Classes of Livestock[a]

	Digestible Energy (kcal/kg)		
Animal	Barley	Corn	Barley % of Corn
Swine	2,817	3,275	86
Cattle	2,574	2,829	91
Sheep	2,767	3,047	91

[a] From Newman et al (1981); NAS-NRC (1979).

animal. This energy is mainly derived from starch and sugars, which constitute about 65% of the weight of grain (Pomeranz 1973). Digestible energy therefore is the key ingredient, and improving this trait should be the major objective in developing feed barley. Figure 1 illustrates that hulled barley, like hulled oats, another major feed grain, is low in ME, protein, and lysine for the promotion of growth and production in swine. Swine raised to marketable weights require 2,800–3,200 kcal/kg ME, 15–16% protein, and 0.6–0.7% lysine (NAS-NRC 1979). Barley diets for swine therefore need to be supplemented for ME, protein, and lysine from external sources. Feeding and malting qualities are not always compatible, as shown by quality criteria described in Table IV for feed and malting barleys. The quality requirements in malting barley are well defined. A malting barley must be hulled, because the hull protects the germinating embryo (coleoptile or acrospire) from mechanical injury during malting and contributes to a more uniform germination of kernel, and to flavor of malt and beer (Dickson 1979). It must have a high germination capacity, 9–12% protein on a dry basis (BMBRI 1977), high diastatic power to convert the carbohydrates into fermentable sugars, and low polyphenols and β-D-glucans. These criteria have little relevance (except β-glucans for poultry) in feed barley. A feed barley need not be hulled, nor has it constraint on protein content like malting barley. A hull-less barley containing 15% protein on average, and one-third more lysine than present in normal barley, will make a superior feed grain to corn. This level of protein does not reduce starch content of barley nor lower its DE (Bhatty et al 1975). Improvements in the protein and lysine contents of hull-less barley are now distinctly possible because of the discovery of Hiproly barley (Munck et al 1969, 1970) and the development of other high-protein and high-lysine mutants of barley (Bansal 1970, Ingversen et al 1973, Doll 1973, Doll et al 1974). Feed barley should be free of β-D-glucans and possibly tannins and polyphenols because of their deleterious effects in poultry nutrition.

Nutritional Value of Barley for Swine

Many studies have been reported in the literature on the DE values of hulled and hull-less barley for swine. Bhatty et al (1974) analyzed 29 cultivars of barley (17 two-rowed and 12 six-rowed), representing a broad range of germ plasm available in Canada, for a number of physical and chemical characters and determined their DE by feeding mice. None of the characters analyzed were correlated to DE, and the barley cultivars could not be distinguished on the basis of energy digestibility. A similar conclusion was reached from another study (Bhatty et al 1975) in which the

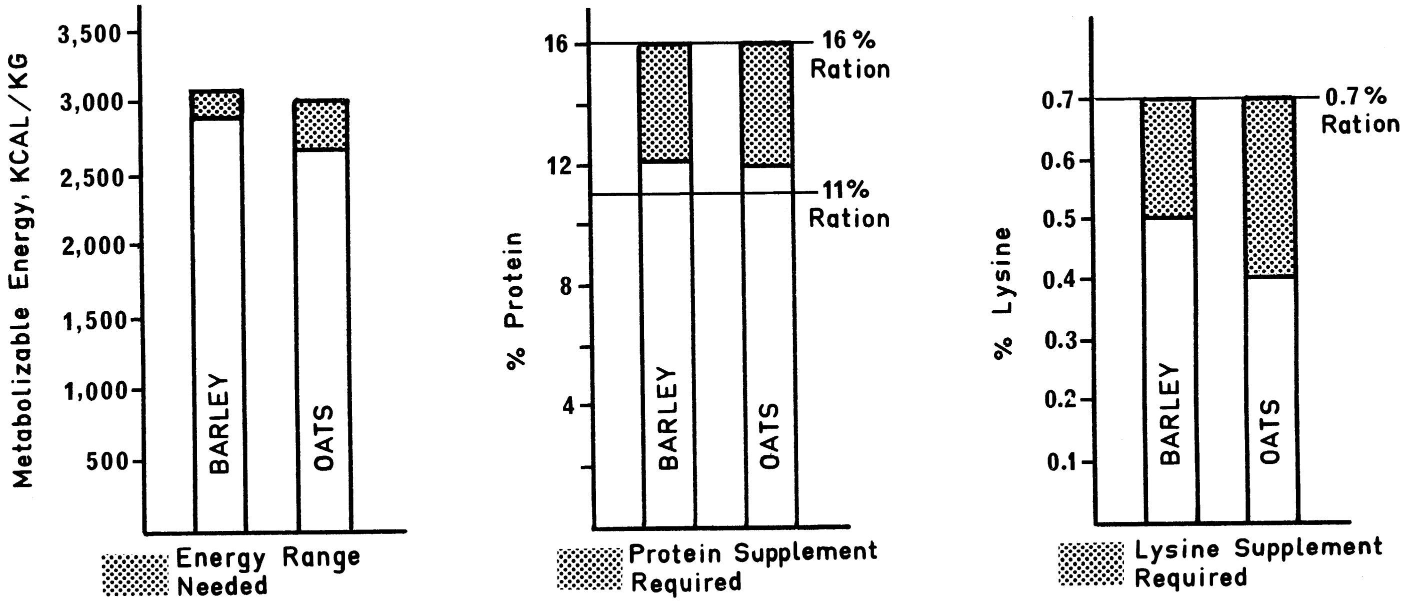

Fig. 1. The metabolizable energy, protein, and lysine contents of hulled barley and oats, and their levels required by swine. (Adapted from Canada Grains Council-Feed Grains of Canada 1970, with permission of the publisher.)

DE of eight pairs of barley having extreme variability in physical and chemical characters was, except for the hulled and hull-less pair, similar. The data obtained from mouse-feeding studies and a subsequent one using swine as experimental animals (Bhatty et al 1979) are summarized in Table V. These studies showed that hull-less barley had substantially more DE than hulled barley for swine and that the difference in DE between the two forms of barley was nearly equal to the difference between hulled barley and corn. Thus, by eliminating hull alone, the DE of barley may be increased by 10–15%.

The DE of hull-less barley may be further improved by increasing its lipid content from the present level of about 2.0% (Bhatty et al 1974) to 3.0 or possibly 4.0%. This requires a genotype of barley having a stable and considerably higher lipid content than is present in adapted cultivars. Risø 1508, a high-lysine mutant of barley, was found to contain 40–65% more lipids than the Canadian barleys (Bhatty and Rossnagel 1979). This genotype is being crossed with Canadian barleys to improve their lipid content. As yet no high-lipid, plump barley has been developed.

The superiority of hull-less barley over hulled barley for swine has been reported in a number of previous studies (Larson and Oldfield 1961; Gill et al 1966; Newman et al 1968, 1980; Mitchell et al 1976; Bell et al 1983). One of the earliest studies was conducted by Joseph (1924), who reported that hull-less barley was clearly superior to hulled barley and equal to corn in feeding value for swine. In spite of such unequivocal evidence, hull-less barley did not become popular with swine nutritionists. The probable reasons were: lack of available hull-less barley in sufficient quantities, lack of incentives for farmers to grow hull-less barley to compensate for its low yield, and most important of all, lack of attention by agricultural scientists in developing high-yielding, stable cultivars of hull-less barley. This situation is likely to change now that there is renewed interest in the development of feed barley. For the first time in North America, two hull-less cultivars of barley (Scout, two-rowed, and Tupper, six-rowed) have been licensed (Rossnagel et al 1983, 1985). Interest in the development of feed barley is also apparent from the published proceedings of the international barley genetics symposia. The first symposium proceedings in 1963 did not contain a single contribution on feed quality of barley, the second in 1970 contained one contribution, and the fourth in 1981 contained 13 contributions.

Nutritional Value of Barley for Poultry

Hulled barley has the same disadvantages for poultry as for swine. Its ME is low compared to that for wheat and corn largely because of hull, although other factors may also be responsible. Poultry feed should provide 2,900–3,300 kcal/kg, but the ME of hulled barley is 2,750 kcal/kg compared with the 3,320 kcal/kg of

TABLE IV
Desirable Quality Criteria in Malting and Feed Barley

Malting Barley[a]	Feed Barley
Must be hulled	May not be hulled
High germination capacity	High digestible/metabolizable energy
High diastatic power	High protein (⩾15%)
Low protein (9–12%)	Improved protein quality (high lysine)
Absence of β-D-glucans and polyphenols	Absence of β-D-glucans and polyphenols (?)

[a] From Dickson (1979) and BMBRI (1977).

TABLE V
Digestible Energy (kcal/kg) of Hulled and Hull-less Barley Determined by Feeding Mice and Swine[a]

Cultivar Type	Mice	Swine
Hulled	3,505 (39)[b]	2,962 (2)
Hull-less	3,918 (6)	3,398 (2)
Difference between hulled and hull-less	413	436
Difference between hulled barley and corn[c]	···	458

[a] Summarized from Bhatty et al (1974, 1975, 1979).
[b] Figures in parentheses indicate number of genotypes used.
[c] See Table III. Wide variations have been reported in the literature for this value.

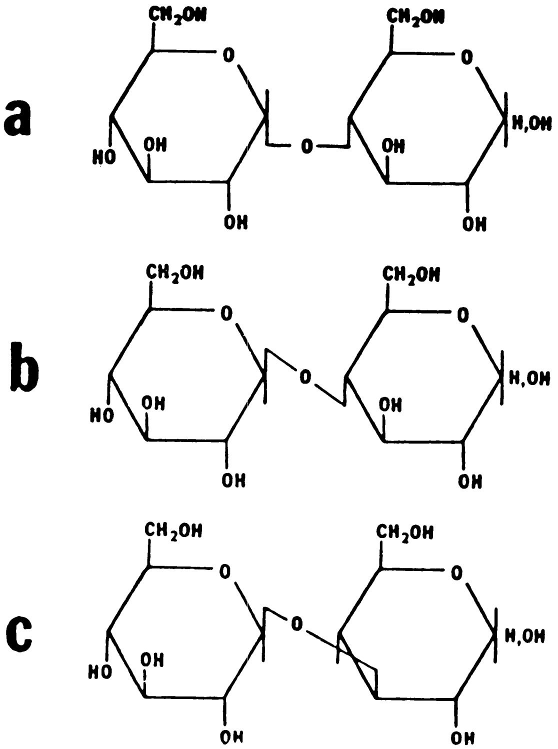

Fig. 2. Glucosyl bonds in starch and β-D-glucans: **a,** α(1→4); **b,** β(1→4); **c,** β(1→3). Reprinted from Bamforth Brewers Digest 22:27, 1982, with permission of the author and publisher.

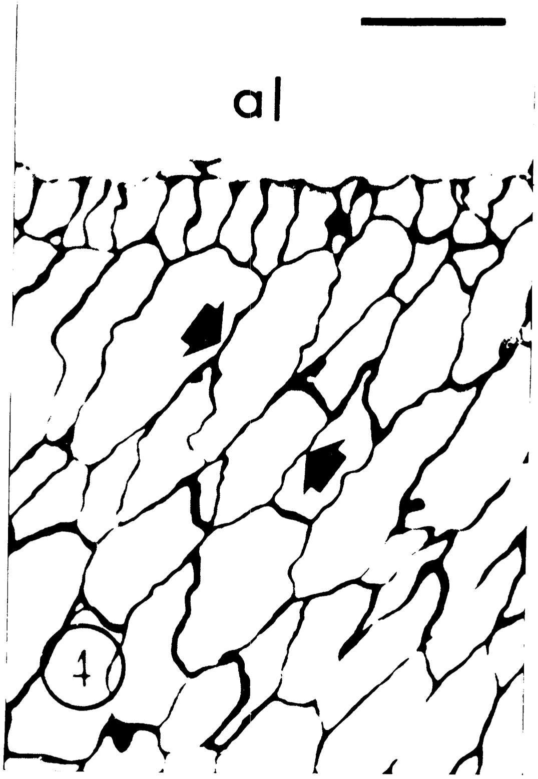

Fig. 3. Fluorescent microscopy of calcofluor-treated barley showing intensely stained β-D-glucans in the endosperm cell walls (arrows): **al,** aleurone layer. Bar 120 μm. Reprinted from Fulcher et al, Food Technology, 1984, 38(1):101-106, with permission of the authors and publisher. Copyright © by the Institute of Food Technologists.

corn and the 3,250 kcal/kg of wheat. Some of the earliest work (Fraps 1946) reported hulled barley to contain about 70% and dehulled barley 82% of the productive energy of corn for poultry. Later studies (Fry et al 1958, Anderson et al 1961) also reported lower feeding quality of hull-less and pearled barley compared to corn for growing chicks. The poor utilization of hull-less barley by young chicks in these studies was ascribed to poor availability of carbohydrates other than crude fiber in barley (Fry et al 1958). These carbohydrates were most likely the nonstarchy polysaccharides, β-D-glucans, or gums that barley (hulled and hull-less) contains from 2 to 10% by weight (Wood 1984). Unlike α-glucan or starch, which contains $\alpha(1\rightarrow4)$ glucosyl bonds, β-D-glucans contain a mixture (30:70) of $\beta(\rightarrow3)$ and $\beta(1\rightarrow4)$ glucosyl bonds (Fig. 2). Because of the mixture of glucosyl bonds, β-D-glucans are less tightly folded and partially soluble in water (Bamforth 1982). They increase the viscosity of intestinal fluids, thereby impairing nutrient absorption and water relationships in the digestive tract of young chicks (Classen et al 1985). The β-D-glucans are primarily present in the endosperm cell walls and are selectively stained by congo red and by calcofluor, a fluorescent whitening agent, and can be observed under a fluorescent microscope (Fig. 3). β-D-glucans are hydrolyzed by malt enzymes. β-glucan solubliase releases soluble glucans from the endosperm cell walls that is converted by endo-β-glucanase into tri- and tetra-saccharides (Bamforth 1985). Commercial enzyme preparations from *Bacillus subtilis* (Zymobest; Premier Malt Co., Milwaukee, WI), *Aspergillus niger* (Sigma Chemical Co., St. Louis, MO), *Trichoderma viride* (Miles Laboratory Inc., Elkhart, IN), and other sources have been employed to improve the nutritional quality of barley used for poultry feeds (Jensen et al 1957, Laerdal et al 1960, Anderson et al 1961, Burnett 1966, White et al 1981, Hasselman et al 1981, Classen et al 1985).

Only a few studies have been conducted on the use of hull-less barley in poultry feeds. One of the earliest studies was that of Anderson et al (1961) who reported that hull-less barley was inferior to corn for growing chicks. More recent studies on the use of hull-less barley in poultry feeds have been conducted by Classen et al (1985). In experiments conducted with roosters (adult birds), the true ME of three genotypes of hull-less barley was equal to that of wheat and superior to hulled barley (Table VI). In another experiment, hull-less barley fed to laying hens at 0–80% levels had no deleterious effects on their performance (Table VII). Average egg production, egg weight, and specific gravity of eggs were similar or better than those obtained from hens fed wheat. These results were in general agreement with data reported in earlier studies on the feeding of hull-less barley to laying hens (Anderson et al 1960, Gillaume 1977). These experiments clearly suggested that hull-less barley could be safely substituted for wheat in feeds for roosters and laying hens. However, hull-less barley included at 0–60% levels in the diet of three-week-old broiler chicks caused a linear decrease in body weight, fat and starch absorption, and in tibia ash (Table VIII). These deleterious effects were caused by β-D-glucans, which were completely removed when hull-less barley was treated with cellulase 5000 (Miles Laboratories Inc., Elkhart, IN), a crude enzyme preparation containing β-D-glucanases, lincomycin (an antibiotic), and by gamma irradiation with cobalt 60 (10 Mrad) (Table IX). Only autoclaving reduced the nutritional value of hull-less barley, most likely because of heat-induced destruction of endogenous β-glucanases that otherwise retain activity into the chick intestine and hydrolyze β-glucans. Gamma rays, like X-rays, have short wavelengths and are capable of hydrolyzing the $\alpha(\rightarrow4)$ glucosidic bonds in starch and the $\beta(1\rightarrow3)$ and $\beta(1\rightarrow4)$ bonds in β-D-glucans (Urbain 1984, MacArthur et al 1984). Gamma irradiation was also reported to improve the feeding value of rye for broiler chicks (Campbell et al 1983, Patel et al 1980) where soluble pentosans rather than β-D-glucans lead to problems similar to those found in barley. The role of lincomycin

TABLE VI
Comparisons of True Metabolizable Energy (TME) of Wheat, Hull-less Barley, and Hulled Barley for Roosters[a]

Cereal	Cultivar Examined	TME (kcal/g)[b]
Wheat	1	3.71 ± 0.07 b[b]
Hull-less barley	3	3.64 ± 0.03 b
Hulled barley	3	3.47 ± 0.05 c

[a] From Classen et al (1985).
[b] Values followed by unlike letters differ significantly ($P < 0.05$).

TABLE VII
Effect of Hull-less Barley Level (Scout) in the Diet on the Performance of White Leghorn Hens[a]

Production Characteristic	Hull-less Barley in Diet (%)					
	0	20	40	60	80	SEM
Percent hen-day egg production	79	82	80	78	79	±0.7
Daily feed intake (g/hen day)	111	110	107	103	105	±0.8
Feed conversion	1.71	1.64	1.61	1.60	1.61	±0.0
Egg weight (g)	54.4	54.9	55.3	55.7	55.1	±0.2
Egg specific gravity	1.081	1.081	1.082	1.082	1.082	±0.000

[a] From Classen et al, unpublished data.

TABLE VIII
The Influence of Level of Dietary Hull-less Barley on Body Weight, Bone Ash, and Retention of Fat and Starch in Three-Week-Old Broiler Chicks[a]

Hull-less Barley in Feed (%)	Three-Week Body Weight (g)	Feed Gain	Tibia Ash (%)	% Retention	
				Fat	Starch
0	464 ± 8	1.66 ± 0.06	60.1 ± 0.7	77.0 ± 0.8	93.7 ± 0.12
20	446 ± 8	1.64 ± 0.02	58.2 ± 1.1	71.8 ± 3.3	···
40	416 ± 15	1.77 ± 0.02	58.4 ± 0.7	67.9 ± 1.5	···
60	404 ± 12	1.68 ± 0.03	57.5 ± 1.1	65.7 ± 2.3	84.1 ± 0.81

[a] Taken from Classen et al (1985). Significance levels: body weight ($P < 0.01$), feed gain (not significant), tibia ash ($P < 0.10$), fat and starch retention ($P < 0.01$).

TABLE IX
The Influence of Hull-less Barley Treatments on Broiler Three-Week Body Weight, Bone Ash, Feed-to-Gain Ratio, and the Absorption of Fat and Starch[a]

Treatment	Three-Week Body Weight (g)	Feed Gain	Tibia Ash (%)	% Absorption	
				Fat	Starch
Untreated (control)	404 c[b]	1.68 a	57.5 a,b	65.7 b	84.1 a
Irradiated grain	484 a	1.61 a	59.1 a,b	72.6 a	85.4 a,b
Lincomycin addition	474 a	1.66 a	61.5 a	75.2 a	87.4 a,b
Cellulase 5000	445 b	1.61 a	57.9 a,b	77.6 a	88.8 b
Autoclaved	270 d	2.26 b	54.1 b	66.2 b	87.8 a,b
SEM[c]	9	0.07	1.9	1.5	1.2

[a] From Classen et al (1985).
[b] Values followed by different letters differ significantly according to Duncan's multiple range test ($P < 0.05$).
[c] SEM = standard error of the mean.

TABLE X
Influence of Gamma Irradiation and Cellulase 5000 Treatment on the Viscosity of Commercial β-D-Glucan[a]

Treatment	Viscosity (sec)
β-D-glucan	
Untreated	408
Irradiated	150
Treated with cellulase 5000 for:	
15 min	205
30 min	159
60 min	157
120 min	154

[a] From Classen et al (1985).

in improving the utilization of hull-less barley by broiler chicks cannot be explained with certainty. It must, however, relate to some influence on chick intestinal microflora that are affected by β-D-glucan-induced changes in intestinal viscosity. The irradiated barley completely lost its characteristic viscoamylograph properties (Fig. 4). The hydrolytic effects of gamma irradiation and cellulase treatment on barley β-D-glucans were confirmed by irradiating and reacting a commercial preparation of β-D-glucan (Biocon Ltd., Cork, Ireland) with cellulase 5000 and measuring its viscosity. The viscosity value of irradiated β-D-glucan was reached after treating it with the enzyme preparation for 0.5–2 hr (Table X).

Improvements in the nutritional quality of hull-less barley for broiler chicks by treatment with gamma irradiation may not be practical. Until β-D-glucan-free cultivars of hull-less barley are available, partial or complete hydrolysis of these nonstarchy polysaccharides may be obtained by treatment with exogenous enzymes (Classen et al 1985). The crude enzyme preparations are relatively cheap and can be directly mixed with the grain. The preparations are stable under a variety of conditions. An enzyme preparation from *B. subtilis* was 80% stable to steam pelleting, 10 min exposure to 60° C temperature. The enzyme activity was even present throughout the gastrointestinal tract of broilers fed supplemented diets (Classen et al, *unpublished data*).

In addition to β-D-glucans, both hulled and hull-less barley contain polyphenols and tannins that may further limit their nutrient availability for poultry. The evidence on the deleterious effects of tannins for poultry is not conclusive. Tannins bind proteins by hydrogen bonding and through hydrophobic interactions (Hahn et al 1984, Oh et al 1980). Coon et al (1979) found no correlation between tannin content and chick weight gain in 122 cultivars of barley. Gohl and Thomke (1976) reported a negative correlation between protein digestibility and tannin content of Swedish barley fed to commercial hybrid layers, although such a correlation does not prove the deleterious effects of tannins. Tannic acid fed to day-old broiler chicks at the 0.5% level caused growth depression (Vohra et al 1966). A more recent study (Newman et al 1984) reported faster weight gain and more efficient feed utilization in one-day-old chicks fed a proanthocyanidin-free barley (ANT 13-13) than those fed regular barley. Regular barley contains low levels of tannins (<0.1% by weight; R. S. Bhatty, *unpublished data*), and it is doubtful if such levels have measurable effects on poultry performance.

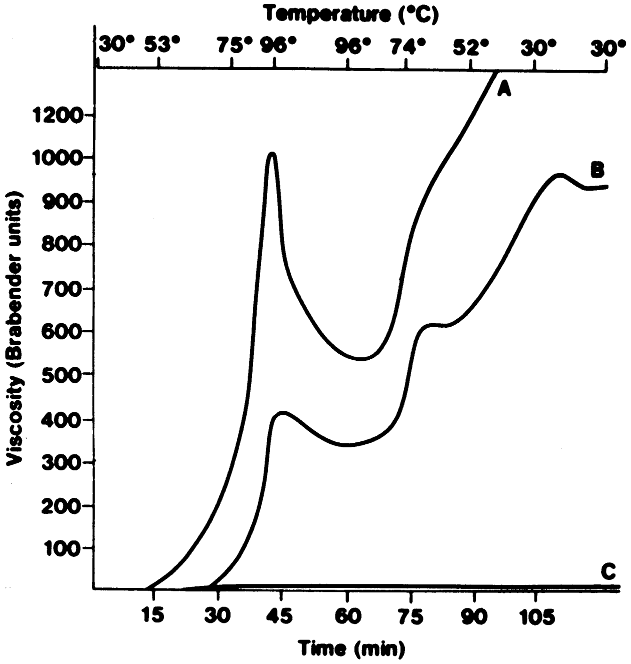

Fig. 4. Viscoamylogram of hull-less barley meals: **A,** autoclaved at 121° C for 20 min; **B,** untreated; **C,** gamma irradiated. From Classen et al (1985), with permission of the authors and the Agricultural Institute of Canada, Ottawa.

Food Uses of Barley

Although barley was used as a bread grain in ancient Europe, only during World War II was some dehulled barley flour (10%) allowed as a wheat flour extender in Britain (Kent 1975). In Korea and Japan pearled barley is primarily used as rice extender. In western countries small quantities of barley continue to be used in breakfast cereals, as soup thickener, as malted flakes, and in special diets for infants and geriatrics (Briggs 1978). In addition to these specialty uses, barley must gain acceptance in other human foods. Many commercial barley products such as fine and medium pearled barley, barley grits, flakes, barley malt, and malt flour are available on the market. Hull-less barley offers the advantage that it can be directly milled and suitably sieved to obtain a meal, pearled and ground to obtain pearled flour, milled, and malted. Barley flour may be incorporated into foods such as muffins, biscuits, unleavened flat bread, noodles, and other bakery and nonbakery products.

Milling of Hull-less Barley

Hull-less barley can be milled to about 73% extraction yield using conventional equipment available for wheat milling (Table XI). The data show that one-step tempering to 11–12% moisture gave the best flour yield. Short tempering for 1 hr to 12% moisture or dry milling of the grain (9.9% moisture) gave somewhat lower flour yields. In barley milling, there is poor separation of bran from the shorts. Even under longer tempering (16–22 hr) bran yield was less than 1%, and the short fraction varied from 26 to 33% of the total of the three fractions (bran, shorts, and flour). However, flour yield of hull-less barley may vary considerably. McGuire (1979) reported flour yields of 50.5–72.2% in 16 hulled, hull-less, two-, and six-rowed cultivars of barley. Hull-less barley flour had almost the same whiteness as wheat flour, although it contained twice the amount of crude fiber normally present in wheat flour (Bhatty 1986). Chemical bleaching of barley flour may be desirable under certain conditions. Under conditions of large-scale or commercial milling of hull-less barley, tempering conditions need to be established, and some milling equipment modifications may be necessary. Hull-less barley is a soft grain. As determined with a Brabender micro hardness tester, its hardness was 136 sec compared to 27 sec for a hard wheat (Glenlea). It should therefore be milled under conditions normally used for milling cookie and pastry wheats.

Table XII shows some of the properties of flour milled from two cultivars of hull-less barley (Scout and Tupper) under laboratory conditions. Not all of these properties are comparable to those of bread wheat flour. Only 5–10% of barley flour may be added to wheat flour to obtain bread of acceptable loaf volume and appearance even in the presence of dough improvers (Kim et al 1978, Cheigh 1979, Bhatty 1986). In another study (Kim and Lee 1977) a combination of 1% glycerolmonosterate and 0.5% calcium stearyl lactylate increased loaf volume of a hull-less barley/wheat composite flour mixed in the ratio of 3:7 to that of bread produced

TABLE XI
Flour Yield (%) of Scout and Tupper Hull-less Barley Tempered to Various Moisture Levels and Milled in an Allis-Chalmers Experimental Mill[a]

Tempering Moisture (%)	Bran	Shorts	Flour			Total
			Break	Reduction	Clear	
11	0.2 ± 0.0	26.7 ± 0.7	29.1 ± 0.7	36.5 ± 0.1	7.6 ± 0.1	73.2 ± 0.7
12	0.2 ± 0.0	27.6 ± 0.6	32.2 ± 0.5	32.4 ± 1.0	7.5 ± 0.1	72.1 ± 0.6
13	0.4 ± 0.0	30.2 ± 0.2	32.0 ± 0.1	29.7 ± 0.4	7.8 ± 0.2	69.4 ± 0.2
14	0.7 ± 0.2	30.8 ± 0.6	32.8 ± 1.3	28.4 ± 1.0	7.4 ± 0.5	68.6 ± 0.8
Short tempering[b]	0.4 ± 0.0	32.8 ± 0.3	27.7 ± 1.0	31.0 ± 1.3	8.2 ± 0.6	66.9 ± 0.3
Dry milling[c]	0.1 ± 0.0	29.7 ± 0.1	28.6 ± 0.5	33.2 ± 0.6	8.4 ± 0.2	70.2 ± 0.1

[a] From Bhatty (1986).
[b] Tempering time 1 hr; tempering moisture 12%.
[c] Grain moisture, 9.9%.

from standard wheat flour. It is likely that hull-less barley flour additions greater than 5–10% will dilute wheat gluten and weaken its viscoelastic properties.

Malting of Hull-less Barley

Food malts are traditionally prepared from wheat and hulled barley (Hickenbottom 1983). The hulled barley malt cannot be directly used in food products because of its high fiber. The malt is mashed and the wort is concentrated to obtain a malt extract for incorporation into food products. Hull-less barley malt can be used like wheat malt. A number of studies has reported on the suitability of hull-less barley for malting (Ballesteros and Piendle 1977, Rennecke and Sommer 1979, Singh and Sosulski 1985). A comparison of the properties of a five-day malt prepared from hull-less barley (Scout) and wheat (Glenlea) is given in Table XIII. The data show that hull-less barley can produce malt of comparative quality with a steeping time one-third shorter than that of wheat. Such a low steeping time would be of special interest to food maltsters.

Pearling of Hull-less Barley

The desirable criteria for pearling barley outlined by Bae (1979) were: shallow crease of barley caryopsis, white aleurone, large plump kernel, gelatinization temperature close to that of rice, and waxy endosperm (high amylopectin) to give a glutenous or sticky pap.

The amylose/amylopectin ratio of starch determines its consistency and water uptake. Waxy starches have high swelling power, and therefore waxy, hull-less barley will produce a soft and glutenous pearled product, whereas a nonwaxy, pearled barley will result in a drier and harder product (Munck 1981). Normal barley starch contains 25% amylose and 75% amylopectin. Barley germ plasm containing a wide range of amylopectin is available (Eslick 1979), although genotypes containing high (80–90%) amylose have not yet been found. The waxy character is controlled by a single gene, which may be produced in mutants by treatment of hull-less barley with a chemical mutagen such as diethylsulfate.

TABLE XII
Physical and Chemical Properties of Hull-less Barley Flour[a]

Character	Flour
Color, Hunter lab color difference meter (*L*)	88.8–90.7
Agtron (546 nm)	48–61
Protein (N × 6.25)	16–17
Ash	1.1–1.4
Lipids	1.8–2.1
Fiber	1.0–1.2
Water hydration capacity, ml/g	1.6–1.8
Alkaline water retention capacity, % wt. gain	281–306
Fat absorption, %	68–91
Pasting temperature, °C	64–66
Peak viscosity, BU	260–335
Viscosity after cooling to 50°C, BU	530

[a] From Bhatty (1986).

TABLE XIII
Comparative Characteristics of Hull-less Barley (Scout) and Wheat (Glenlea) Five-Day Malts[a]

Character	Hull-less Barley	Wheat
Germination energy,[b] %	98 ± 1	95 ± 2
Water sensitivity,[b] %	1 ± 0	3 ± 1
Steeping time (44% moisture), hr	48	72
Diastatic power, °L	79 ± 9	86 ± 3
α-Amylase activity, SKB units/g malt	18.8 ± 1.5	19.9 ± 0.8
Soluble nitrogen, %	0.84 ± 0.07	1.08 ± 0.01
Hot water extract, %	83.9 ± 0.7	82.4 ± 0.2
Modification index, %	32.2 ± 2.9	44.5 ± 0.3

[a] Data from Singh 1983.
[b] Of grain.

Normal barley starch granules are spherical or lenticular, with a gelatinization temperature range of 51–60°C compared to polygonal granules of rice starch with a gelatinization temperature range of 68–78°C (Lineback 1984). A gelatinization temperature range of 53–83°C has been reported for barley (Bae 1979). Thus it may be possible to alter both the starch composition of hull-less barley as well as its gelatinization temperature to match that of rice.

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