POTENTIAL OF HULLESS WINTER BARLEY AS AN IMPROVED FEED CROP

Robert L. Paris

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Dr. Carl A. Griffey, Chairman
Dr. Daniel E. Brann
Dr. Glenn R. Buss
Dr. Eluned C. Jones
Dr. Jeannine M. Harter-Dennis
Department of Agriculture
Univ. of Maryland Eastern Shore

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(ABSTRACT)

This research was conducted to determine the potential of hulless winter barley (*Hordeum vulgare* L.) as an improved feed crop in the mid-Atlantic region. Winter barley is an excellent crop in rotation with soybean (*Glycine max* L.); however, production of winter barley during the past few years has decreased mainly due to low market prices, even though the mid-Atlantic region is a feed grain deficient area. Therefore, value added traits need to be developed in order for barley production to continue in the region.

In the first part of this study, the objectives were to: (i) evaluate the agronomic performance and potential of six experimental hulless winter barley lines compared with two commercial hulled cultivars; (ii) determine and compare fiber, β-glucan, protein, and fat concentrations, and true metabolizable energy, corrected for nitrogen (TME_n) among these genotypes; and (iii) evaluate the genetic potential of winter hulless barley accessions from the world collection for use as parents in hulless breeding programs. Six hulless lines all derived from the cross VA75-42-45/SC793556//CI2457 were acquired from Clemson University in South Carolina. The six lines were evaluated for yield, test weight, heading date, plant height, and lodging. These hulless lines along with two hulled cultivars were planted in replicated yield plots in four states with a total of eight locations, and were managed according to standard recommended practices. Grain from each of the hulless lines and hulled checks, along with that of Trical 498 triticale (X *Triticosecale*) and Jackson wheat (*Triticum aestivum* L.) were analyzed for fiber, β-glucan, fat, protein, and ash concentration, and TME_n value. Eight hundred and seven winter or

facultative habit hulless barley lines were obtained from the USDA-ARS National Small Grains Collection in Aberdeen, ID. These lines were screened for reaction type to races 8 and 30 of barley leaf rust (*Puccinia hordei*) and to a composite population of powdery mildew (*Blumeria graminis* f. sp. *hordei*). These accessions also were planted in observation rows to evaluate heading date, plant height, lodging, and seed threshability.

The hulless lines yielded 23% less, but had 13% higher test weights than the hulled check cultivars. There was no difference between hulled and hulless barley in heading date and plant height. Hulless lines had a higher protein and lower fiber concentration than hulled barley. They also had higher β-glucan and fat concentrations than triticale or wheat. TME_n was similar between hulled and hulless barley, triticale, and wheat. Approximately 100 hulless barley lines from the world collection were selected for potential use as parents among 800 accessions tested, based on evaluations of lodging, plant height, threshability, and seed color.

In the second part of the study the objectives were to determine the effects of (i) hulled and hulless barley, and (ii) β-glucanase on the performance of broilers fed different diets from 21 to 42 days of age. Diets comprised of 30% hulless or hulled barley, and a standard corn (*Zea mays*)/soybean meal diet with and without β-glucanase enzyme were evaluated to determine the effects of barley on gut viscosity, carcass weight, gain, percent shell, and feed efficiency in 21 to 42 day old broilers. In the first year, diets comprised of hulless lines SC890573 and SC860972, and the hulled cultivar Callao were compared to a standard check diet. In the second year SC860972 was replaced with SC880248 due to the inability to secure a sufficient amount of seed. Each year one hulled and two hulless barley diets were compared to a standard diet. Each diet was fed with and without enzyme, for a total of eight diets. Broilers 21 days of age were fed the diets until day 42 when they were processed. There was a significant decrease (P#0.05) in gut viscosity of birds fed diets with enzyme compared to birds fed diets without enzyme; however, gut viscosity did not affect weight gain or percent shell. Barley substituted at the 30% level did not have a significant effect on broiler performance, nor did the addition of enzyme. Absence of enzyme effect was attributed to bird age, since older birds are able to hydrolyze β-glucan more effectively than juveniles.

The potential of hulless barley as an improved feed source for the poultry and swine industry is great for the mid-Atlantic region. Increases in grain yield are currently being realized through focused breeding efforts, and hulless lines exhibit positive nutritional components that combine favorable attributes of both wheat and hulled barley. Barley substituted at the 30% level in the diets of broilers did not cause any detrimental effects. Addition of hulless barley may potentially lead to a reduction in cost per pound of gain of broilers, and provide an alternative crop for mid-Atlantic region grain producers and feeders.

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CHAPTER I

LITERATURE REVIEW

BARLEY HISTORY

Barley belongs to the family *Gramineae*, subfamily *Festucoideae*, and tribe *Hordeae*. Also included in this large family are wheat, rye, corn, millet, and sorghum, which generally have hulless seed, and barley, rice, and oats, which usually have covered or hulled seed. Of these crops, barley is the most widely adapted around the world. It is relatively cold tolerant and of the small-grains is the most drought, alkali, and salt tolerant species. These factors, along with barley s relatively early maturity, make it a very attractive crop for many areas of production. Currently worldwide it is the fourth highest yielding cereal, ranking fifth in total acreage, yet it continues to be under-utilized as a food source and as a feed in diets of monogastric animals. In the East and Far East, hulless barley has been utilized for many centuries, but not until recently has interest been initiated in developing commercial hulless lines for major production in western countries (Nilan and Ullrich, 1993; and Jeroch and Danicke, 1995).

HULLESS VERSUS HULLED BARLEY

The head of a barley plant consists of many spikelets, each of which consists of a floret with two glumes surrounding the developing seed. The dorsal glume (palea) is overlapped along the edges by the ventral glume (lemma), which may terminate in an awn (Duffus and Cochrane, 1993). In hulled barley, a cementing substance secreted during seed development, effectively joins the lemma, palea, and seed into one unit. However in hulless barley, a single recessive gene responsible for the absence of this secretion, allows the glume to readily separate from the seed during threshing (Bhatty, 1986b).

Rossnagel et al. (1981) identified four major criteria required for development of ideal hulless barley genotypes. Hulless barley must have high grain yield, good threshability, minimum embryo damage, and attractive kernel appearance. Compared to hulled barley, hulless barley has been low yielding, even when yield is adjusted for lack of hull. However, this shortcoming is largely attributed to the lack of breeding effort placed on hulless barley, and likely could be rectified given sufficient attention and resources.

Although a single recessive gene controls the hulless trait, threshability is an issue of concern in hulless barley production. For some cultivars the hull threshes off very easily, while in others a large percentage of hulls are retained on the grain. Rossnagel et al. (1981) reported that ease of threshability must be selected for in a cultivar; however, equipment adjustments and harvest conditions also can be a major contributing factor.

Care must be taken during threshing and handling to ensure that the seeds maintain their viability because the embryo lacks protection in hulless barley. General recommendations are to use a closer cylinder-to-concave setting with a slower cylinder speed and increased air-flow. Depending on end-use, additional cleaning may be required in order to remove hulls.

Like hulled barley, hulless barley may be either two-or six-rowed. The pericarp in hulless barley is visible, revealing some unique colors in the grain, ranging from opaque amber to dark purple. However, color of the grain does not affect the nutritional quality, and for animal feed is of less importance than for human consumption where specific aesthetically pleasing colors may be desirable.

There are also some differences in grading standards of hulless barley compared to traditional hulled barley. The hull constitutes 10 to 13% of the dry weight of barley grain and 33% of the total volume, accounting for an increase in test weight from 618 kg m^{-3} for hulled barley to 772 kg m^{-3} in hulless barley. Quality standards of hulless barley for human consumption require grain with less than 5% hulls and a test weight of 772 kg m^{-3}, while standards for feed quality require grain with a hull content of 15% or less, and a test weight of 741 kg m^{-3} (Bhatty, 1986b; McLelland, 1998).

NUTRIENT COMPOSITION

Protein

Protein concentrations of hulled barley range from 8.5 to 21.2% among genotypes with a mean of 13.1%, and can vary by as much as 6.6% within genotypes due to environmental effects (Bhatty, 1993; Torp et al.,1981). Hulless barley also varies widely in protein concentration; however, Jaikaran et al. (1998) reported that hulless barley on average has a 1 to 2% higher protein concentration than hulled barley. Despite this large range, protein concentration of feed barley is 12% on average. This is due in part to the extensive use of low-protein malting barley for feed. Development of high-protein feed barley has been pursued, but efforts to improve protein quantity in barley have not been very successful due to the negative relationships between protein and starch, protein and lysine, and protein and grain yield. Thus, it appears that the potential to increase protein quantity simultaneously with other traits of importance through breeding is very limited (Bhatty, 1993; Bhatty and Rossnagel, 1981).

Starch

Hulled barley starch concentrations comprise 58 to 64% of the grain (MacGregor and Fincher, 1993), with 95 to 100% digestibility in poultry, swine, and cattle (Bhatty, 1993). Starch consists of two major components, amylose and amylopectin. Amylose, usually present in lower amounts, is mainly comprised of long α-(1$\rightarrow$4)-linked D-glucose residue chains, while amylopectin, the major component of most starches, is comprised of long α-(1$\rightarrow$4)-linked D-glucose residue chains interconnected through α-(1$\rightarrow$6) bonds. Normal barley starch contains approximately 20-30% amylose and 70-75% amylopectin. Traditionally, amylose values have ranged from less than 1% in waxy types to 45% in high-amylose (starchy) types; however, Bhatty and Rossnagel (1997) have recently developed a zero amylose line by crossing two waxy types. Waxy type barley is desired for human consumption, while starchy type barley is generally desired for feed. However, there has recently been some disagreement over the effect of starch type on digestibility (Bhatty, 1993).

Starch can be classified as either waxy (low amylose) or starchy (higher amylose) using a technique known as iodine staining. Amylose binds with iodine, causing the seed to turn dark purple, while amylopectin binds very weakly resulting in a light red/pink color (MacGregor and Fincher, 1993; Berlyn and Miksche, 1976). Through this process, the phenotypes of large numbers of lines can be rapidly characterized as waxy or starchy.

β-glucan

A component of barley making it unpopular as a feed for swine and poultry is the nonstarch polysaccharide mixed-link β-glucan. The concentration of β-glucan varies considerably depending on genotype and growing conditions. Extended periods of hot, dry weather just prior to harvest have been found to greatly increase β-glucan concentrations. Concentrations range from 2 to11% but usually average 4 to7%, with two-rowed barley generally containing a higher concentration of β-glucan than six-rowed barley (Bhatty, 1993). This polysaccharide forms linear chains of β-glucosyl residues polymerized through mixed-(1→3) and (1→4) linkages, which on average, consist of 70% (1→4) and 30% (1→3). These linkages are not dispersed randomly throughout the chain, but are arranged such that each (1→3) linkage is separated by one or more (1→4) linkage(s), causing the chains to become kinked and reducing the overall compaction of the molecule. Combination of the rigid, ribbon-like (1→4) chains with the flexible (1→3) linkages results in chains that are extremely asymmetrical and more water-soluble, thus readily forming viscous gels (MacGregor and Fincher, 1993; McNab and Smithard, 1992).

Barley endosperm cell walls consist of 75% β-glucans, 20% arabinoxylan, and very small amounts of cellulose, glucomannan, phenolic acids, and protein. Within the starchy endosperm, (1→3) and (1→4)-β-glucan concentrations are very high, and low energy fibrillar and cellulosic materials are present at very low concentrations. Conversely, the hull and other outer layers of barley grain consist of cell wall remnants in which cellulose, silica, and lignin contents are very high, and the (1→3), and (1→4)-β-glucan concentrations are very low. During the germination phase, cell walls must be completely degraded in order to mobilize starch and other stored nutrients. The scutellum is responsible for synthesizing β-glucanase, which degrades β-glucan in the cell walls.

Treatments to hydrolize β-glucan bonds in feed products include irradiation, water treatment and drying, and enzyme addition. The use of irradiation has not been very promising, and it is doubtful if any significant progress will be made in this area. Water treatments have had some measure of success; although, the mechanisms in this process are not fully understood. It is possible that the soaking period could cause an enzymatic response in the grain, but it does not seem likely that it is entirely associated with the degradation of β-glucans, since similar results have been reported in other grains (McNab and Smithard, 1992; Bamforth and Barclay, 1993). The most promising treatment is the addition of β-glucanase enzymes, that degrade the endosperm more thoroughly, increasing both available nutrients and nutrient uptake.

BARLEY USES

The three major uses of barley are malt, feed, and food. By far the largest portion of barley (approximately 74%) is used for livestock feed, while only 24% is used for malt production, and only 3% is used directly for human consumption. In Canada only 10% of the malting barley grown is utilized as malt, while 90% is considered to be failed malt, and is used as feed (Bamforth and Barclay, 1993).

MALTING

Malting barley is specifically grown for the purpose of producing malt from germinated barley. Although production of beer and other alcoholic beverages may be the most commonly known use of malt, a large percentage is used in the food industry. Malt, regardless of its end use, is produced in a similar manner by first steeping the grain in water to trigger metabolism and the production of enzymes. As the moisture concentration of the grain increases, cell walls and starchy endosperm are softened, and germination occurs. The grain is kiln dried after uniform moisture and consistency are obtained, effectively stopping germination, while ridding the malt of unpleasant flavors. Care must be taken in drying brewery-malt not to over heat the malt in order for desirable enzymes to survive for later re-activation (Bamforth and Barclay, 1993).

In brewery malting operations the grain must be as uniform as possible and, therefore, ready for rapid and complete modification. This requires grain with high viability (>96%), and low dormancy rates (<4%), coupled with high vigor. Hulled barley with high amylose and low protein concentrations is preferred for the production of brewery-malt. High starch concentrations are critical in providing high levels of sugar to alcohol-producing microbes, and are inversely proportional to protein concentrations (Bamforth and Barclay, 1993; Bhatty, 1986b). The hull protects the embryo, provides uniform germination, and imparts specific flavors and colors to the wort.

Beta-glucan concentration in malting barley is also very important. High concentrations of β-glucan indicate that incomplete cell wall degradation has taken place, and result in lower malt extract values. Also, β-glucan forms highly viscous solutions, causing slowed filtration rates. The undegraded β-glucan may then precipitate out in the product or seriously alter the color and texture. Therefore, the concentration of β-glucanase within the grain is very important to the malting process. In properly stored grain, β-glucanase activity is very low or absent, but after germination is initiated, it rises sharply in one to two days.

FEED

Barley is an excellent source of highly digestible starch and protein for poultry, swine, and cattle. However, high fiber and β-glucan concentrations traditionally have resulted in digestion problems in poultry and swine. Increased fiber may result in decreased feed intake, while β-glucan increases the viscosity of the intestinal fluid because the chains are not broken down. Enzymes required to hydrolyze plant wall polysaccharides such as β-glucans are not produced by monogastric animals, although some action does take place in the hindgut. However, the addition of β-glucanase to the diet alleviates this problem (Fincher and Stone, 1993; MacGregor and Fincher, 1993).

Poultry

When fed to poultry, barley consistently produces less energy and is less digestible than when fed to other livestock, primarily because of problems associated with high fiber and β-glucan (Jeroch and Danicke, 1995). With the use of hulless barley, fiber has been decreased to concentrations found in standard corn/soybean meal diets. However, the antinutritive factors associated with β-glucan are still a problem in hulless barley. Although the effects of β-glucan on the digestive system are not clear, it has been suggested that they interfere with the release of nutrients from the endosperm (Classen et al., 1985; Hesselman and Aman, 1986). Reports of feed-intake depression due to increased gut viscosity and slowing of feed passage have been documented (McNab and Smithard, 1992). A commonly held theory is that increased gut viscosity reduces the mixing of enzymes within the intestines and restricts available nutrients from contacting the intestinal walls for uptake (White et al., 1980). Sticky feces also was thought to be associated with increased gut viscosity, but was later found to be caused by increased microorganism activity produced in the cecum in response to the presence of β-glucan. In order to reduce the concentration of cecal microorganisms in the intestines, it has proven helpful to treat the feed with hydrolyzing enzymes such as β-glucanase, which occur naturally during the germination process (Bhatty, 1993).

Limited use of barley in poultry rations also relates to the high fiber concentration and low metabolizable energy (ME) of barley compared to corn and wheat. Reports of barley ME have been widely variable in the literature due to such factors as grain condition, chemical composition, and experimental procedure used to analyze ME. Different tests have been used, including available metabolizable energy (AME), true metabolizable energy (TME), AME_n, and TME_n (AME and TME corrected to nitrogen equilibrium). These tests all have disadvantages. AME is based on the relative proportion of carbohydrates, lipids, and proteins, while TME varies inversely with the amount of fiber present. As a result, barley that varies in any of these components is subject to varying ME calculations. However, AME_n is most commonly used to express ME (Bhatty, 1993).

Standard ME recommendations of 2899 to 3301 kcal kg^{-1} have been set for poultry diets. The ME of hulled barley generally does not exceed 2751 kcal kg^{-1}, while corn and wheat have average ME values of 3320 and 3250 kcal kg^{-1}, respectively. Therefore, hulled barley has a 5 to 20% deficiency in ME compared to wheat and corn (Bhatty, 1993).

Broilers

Diets high in barley have not been well suited for broilers, which are generally fed a high-energy diet to promote rapid growth and development. Studies of broiler chick diets have indicated that hulled barley is inferior as a feed compared to wheat and corn (Mannion, 1981; Hesselman et al., 1982; Newman and McGuire, 1985). Conversely, Classen et al. (1985) reported that hulless barley had a higher TME than hulled barley, and when treated with β-glucanase had a TME very similar to wheat. Reports of increased energy availability from hulless versus hulled barley have ranged from 25 to 0% (Bhatty, 1993; Newman and Newman, 1988). Bhatty (1993) reported that addition of β-glucanase improves the ME of barley. In fact, most studies do report positive effects on growth rate and digestibilities with the addition of β-glucanase (White et al., 1980; Brenes et al., 1993; Salih et al., 1991; Almirall et al., 1995; Fuente et al., 1995; Friesen et al., 1992). However, there can be large differences in response of cultivars to treatment with β-glucanase, the concentration of β-glucanase in the barley, and the activity of the β-glucanase used (Zhi-Yuan et al., 1995).

Laying Hens

Mature poultry are better able to utilize barley diets due to more efficient digestion of β-glucans (Classen et al., 1988). Jeroch and Danicke (1995) reported that the use of barley in the diets of layers has been increasing in northern Europe, and that the live weight of the birds, not the weight or number of eggs, was affected by the barley. However, some questions still exist concerning the cleanliness of the eggs due to the β-glucans and sticky feces, although the use of β-glucanase seems to alleviate such problems.

Classen et al. (1988) reported that hulless barley is an excellent feed for layers. Hens fed 71 to 80% hulless barley were heavier, and produced larger eggs than hens fed the same amount of hulled barley. They concluded that hulless barley was at least equivalent to wheat and surpassed hulled barley as a feed for laying hens. Gillaume and Calet (1973) substituted standard layer diets with 10, 20, and 30% hulless barley with no negative effects on egg production, egg weight, or feed intake.

Swine

Barley has been a major component of swine diets for many years in various regions of the world, especially in northern latitudes where corn cannot be grown. The value of barley as a swine feed is highly variable and dependent on such characteristics as cultivar, physical characteristics of the grain, and chemical composition (Torp et al., 1981; Bhatty, 1993). Availability of nutrients has also been reported to be altered by the physical condition of the grain at feeding. Goodband and Hines (1988) reported that pigs fed finely-ground hulled barley diets performed better than those fed more coarsely ground diets. However, swine performance on finely-ground barley rations was only 92-100% of those fed the standard milo diet. The difference was attributed to higher fiber content and lower digestible energy (DE) of barley, even though it contains more total protein and non-dispensable amino acids than corn or grain sorghum (Bhatty, 1993).

It has been concluded from several studies that hulless barley when fed to swine has substantially higher DE than hulled barley (Bhatty, 1986b; Mitchall et al., 1976; Gill et al., 1966). Bhatty et al. (1979) conducted a study in which hulled and hulless isogenic lines of barley were grown under identical conditions. The DE of the hulless lines was 14.7% higher than hulled barley lines. Since barley is more commonly fed to swine than poultry, it can be concluded that β-glucan content is not as critical a factor with swine. However, some increases in swine digestibility with the addition of β-glucanase to barley diets have been reported (Li et al., 1996; Jensen et al., 1998; Baidoo et al., 1998).

Ruminants

Barley is very well suited for sheep and cattle as a source of energy and protein. Enzymes required to hydrolyze plant wall polysaccharides such as (1→3) and (1→4)-β-glucans are not produced by vertebrates; however, the microflora and microfauna in the stomachs of ruminants are capable of breaking down such materials. Therefore, very little research has been done on the effect of hulless barley in the diets of cattle and sheep. Recently, however, Yang et al. (1997a) reported that digestibility of hulless barley was low in Holstein cows, even though milk production levels were equivalent to cows fed hulled barley or corn diets. While the net energy for lactation was higher for hulless barley than hulled barley, Yang et al. (1997b) recommended that hulless barley be processed in order to ensure high ruminal digestibilities. Beauchemin et al. (1999) concluded that dairy cows fed hulless barley diets had increased levels of digestible energy and higher milk production compared to cows fed hulled barley diets, and dairy cows fed diets treated with fibrolytic enzyme produced more milk than those fed non-treated diets. Similar conclusions have been recorded for beef cattle, where diets of dry-rolled hulless barley and steam-flaked hulless barley yielded 97 and 102%, respectively, the feed value of steam-flaked corn (Zinn et al., 1996).

FOOD

In Asian countries, hulless barley has been a staple in human diets for many centuries (Leonard, 1947). Recently, interest has increased in utilizing hulless barley as a food for human consumption in western countries. This has primarily been brought about by the association of β-glucan with positive health benefits.

In direct contrast to the negative impact in monogastric animals, β-glucan has been shown to be beneficial as a source of dietary fiber in humans. Beta-glucan is a part of the soluble fiber content of the barley grain which cannot be broken down by mammalian digestive enzymes. The soluble fiber increases the intestinal transit time, delays gastric emptying, and slows glucose absorption. These conditions lower postprandial blood glucose concentrations and decrease blood serum cholesterol. In addition β-glucan has been associated with beneficial effects on hormone responses, colonic cancer, and micronutrient availability (Martinez et al., 1992; Newman and Newman, 1990; Wang et al., 1992). De Groot et al. (1963) were first to show the hypocholesterolemic effects of barley in rats, with reductions in cholesterol level as great as 50%. Qureshi et al. (1980) associated barley with reduced plasma and liver cholesterol in chickens. Chen et al. (1981) and Anderson et al. (1990) reported that barley soluble fiber was responsible for direct reduction in serum cholesterol. Fadel et al. (1987) determined that β-glucan was responsible for reduction in cholesterol levels via feeding two barley cultivars of similar β-glucan concentrations, one with β-glucanase and one without. Reduction in cholesterol level was reported in the diet containing β-glucan only, while no reduction in cholesterol level was reported in the diet containing β-glucanase.

Such strong evidence of health benefits has increased research efforts focusing on food uses of hulless barley (Hudson et al., 1992; Berglund et al., 1992). Boros et al. (1996) reported that the increased concentration of protein in hulless barley made it a superior food for humans compared to hulled barley. Earlier studies indicated that hulless barley flour could be substituted for wheat flour at 5-10% with no adverse affects on bread quality (Bhatty, 1986a), and later studies (Hawrysh, 1996) reported success in bread making with hulless barley flour levels of 50%. Waxy type hulless barleys also have been used successfully in bread-making (Berglund et al., 1992; Hudson et al., 1992). From a different approach, Young et al. (1998) reported success with adding 1% β-glucan to wheat bread with no adverse affects on quality.

Further exploration is needed in the area of hulless barley food malt production. Bhatty (1996) reported that food malt produced from hulless barley was superior to the traditional brewer s malt due to higher protein concentrations, better color, and higher concentration of β-glucan.

CONCLUSIONS

Barley has been found to contain more protein and a better amino acid balance than corn, and as a result, barley-based diets require less protein supplementation (Bhatty, 1993). Although there have been many reports of the superiority of hulless barley over hulled barley and other feed grains, it is still underutilized. This is due in part to the lack of sufficient quantities of hulless barley, lack of suitable cultivars and lack of hulless barley development (Bhatty, 1986b, 1993). It also seems that great potential exists for the use of hulless barley as a major food grain in western countries. As more studies are conducted on the nutritive and health benefits of hulless barley, and as more high-yielding, disease resistant lines are developed, many of the traditional recommendations should be reevaluated.

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CHAPTER II

EVALUATION OF HULLESS WINTER BARLEY AS AN IMPROVED FEED CROP

ABSTRACT

Winter barley (*Hordeum vulgare* L.) is an excellent crop in rotation with soybean (*Glycine max* L.) in the mid-Atlantic region. However, production of winter barley during the past few years has decreased (Fig. 1) mainly due to low market prices (Fig. 2), even though the mid-Atlantic region is a feed grain deficient area. Therefore, value added traits need to be developed in order for barley production to continue in the region. This study was conducted to: (i) evaluate the agronomic performance and potential of six experimental hulless winter barley lines compared with two commercial hulled cultivars; (ii) determine and compare fiber, β-glucan, protein, ash and fat concentrations, and true metabolizable energy corrected for nitrogen (TME_n) among these genotypes; and (iii) evaluate the genetic potential of winter hulless barley accessions from the USDA-ARS hulless barley world collection for use as parents in hulless breeding programs. Six hulless lines all derived from the cross VA75-42-45/SC793556//CI2457 were acquired from Clemson University in South Carolina. The six lines were evaluated for yield, test weight, heading date, plant height, and lodging. These hulless lines along with two hulled cultivars were planted in replicated yield plots in four states with a total of eight locations, and were managed according to standard recommended practices. Grain from each of the hulless lines and hulled checks, along with that of Trical 498 triticale (X *Triticosecale*) and Jackson wheat (*Triticum aestivum* L.) were analyzed for fiber, β-glucan, fat, protein, and ash concentration, and TME_n value. Eight hundred and seven winter or facultative habit hulless barley lines were obtained from the USDA-ARS National Small Grains Collection in Aberdeen, ID. These lines were screened for reaction type to races 8 and 30 of barley leaf rust (*Puccinia hordei*) and to a composite population of powdery mildew (*Blumeria graminis* f. sp. *hordei*). These accessions also were planted in observation rows to evaluate heading date, plant height, lodging, and seed threshability. The hulless lines yielded less, but had higher test weights than the hulled check cultivars. There was no difference between hulled and hulless barley in heading date or plant height. Hulless lines had a higher protein and lower fiber concentration than hulled barley, and exhibited higher β-glucan and fat concentrations than triticale or wheat. There was no difference in TME_n between hulled and hulless barley, triticale, or

wheat. Based on field and greenhouse evaluations of 800 hulless barley lines from the world collection, approximately 100 lines were selected for use as potential parents based on lodging, plant height, threshability, and seed color. The potential for hulless barley as an improved feed component in poultry and swine diets is great for the mid-Atlantic region. Increases in yield are currently being realized as a result of breeding, and hulless lines exhibit positive nutritional components that combine favorable attributes of both wheat and hulled barley.

INTRODUCTION

Winter barley is an excellent crop in rotation with soybean in the mid-Atlantic region. Soybeans can be planted a week earlier following barley. Therefore yields of double-crop soybeans following barley are significantly higher than following wheat. Production of wheat and barley also allows producers to extend the time available for harvesting small grains and planting soybeans, while providing an alternate crop to reduce the buildup of crop-specific pathogens.

The mid-Atlantic region is well situated regarding demands for feed grains in that poultry and swine operations provide domestic demand and local export markets provide foreign demand. However, production of winter barley during the past few years has decreased mainly due to low market prices, even though the mid-Atlantic region is a feed grain deficient area (Fig. 1 and 2). Barley varieties with greater marketability in both domestic and foreign markets are needed to make barley an economical cash crop. Improvements in the feed value of barley such as lower concentrations of fiber and β-glucan and higher metabolizable energy content would make barley more competitive as a feed grain.

The barley head consists of many spikelets, each of which contains a floret with two glumes surrounding the developing seed. The dorsal glume (palea) is overlapped along the edges by the ventral glume (lemma), which may terminate in an awn (Duffus and Cochrane, 1993). In hulled barley, a cementing substance secreted during seed development effectively joins the lemma, palea, and seed into one unit. However in hulless barley, a single recessive gene responsible for the absence of this secretion, allows the glume to readily separate from the seed during threshing (Bhatty, 1986). In the East and Far East, hulless barley has been utilized for many centuries. Only recently have efforts been initiated in western countries to develop commercial hulless lines for major production; however, winter hulless barley cultivars have not been developed for the mid-Atlantic region of the United States (Nilan and Ullrich, 1993).

Rossnagel et al. (1981) identified four criteria for hulless barley development that include high grain yield, good threshability, minimum embryo damage, and attractive kernel appearance. Reduced yields have been commonly associated with hulless barley even when adjusted for lack of hull compared to traditional hulled barley (Bhatty, 1993). Rossnagel et al. (1981) reported that hulless spring barley varieties yielded an average of only 88% of that of hulled check varieties. However, this shortcoming is largely attributed to lack of breeding effort placed on hulless barley, and likely could be rectified given sufficient attention and resources.

In hulled barley the hull constitutes 10 to 13% of the dry weight of barley grain and 33% of the total volume, accounting for the increase in test weight from 617.8 kg m^{-3} to 772.2 kg m^{-3} in hulless barley. Quality standards of hulless barley for human consumption require grain with less than 5% hulls and a test weight of 772.2 kg m^{-3}, while quality standards for feed require a hull content of 15% or less and a test weight of 741.3 kg m^{-3} (Bhatty, 1986; McLelland, 1998).

Average starch concentrations of hulled barley range from 58 to 64%, with 95 to 100% digestibility in poultry, swine, and cattle (MacGregor and Fincher, 1993; Bhatty, 1993). Starch consists of two major components, amylose and amylopectin. Amylose, usually present in lower amounts, is mainly comprised of long α-(1$\rightarrow$4)-linked D-glucose residue chains, while amylopectin, the major component of most starches, is comprised of long α-(1$\rightarrow$4)-linked D-glucose residue chains interconnected through α-(1$\rightarrow$6) bonds. Normal barley starch contains approximately 20 to 30% amylose and 70 to 75% amylopectin. Amylose content of barley starch generally ranges from less than 1% (waxy types) to 45% (starchy types); however, Bhatty and Rossnagel (1997) have recently developed a zero amylose barley line by crossing two waxy types. Such waxy type barley is desired for human consumption, while starchy-type barley is generally desired for feed (Bhatty, 1993). Starch can be classified as either waxy (low amylose) or starchy (higher amylose) using a technique known as iodine staining. Amylose binds with iodine, causing the seed to turn dark purple, while amylopectin binds very weakly resulting in a light red/pink color (MacGregor and Fincher, 1993; Berlyn and Miksche, 1976). Through this process, phenotypes for large numbers of lines can be rapidly characterized as waxy or starchy.

The concentration of β-glucan in barley varies considerably depending on genotype and growing conditions. Extended periods of hot, dry weather just prior to harvest have been found to greatly increase β-glucan concentrations. Concentrations range from 2 to 11% but usually average 4 to 7%, with two-rowed barley generally containing higher concentrations than six-rowed barley (Bhatty, 1993).

The nonstarch polysaccharide component, mixed-link β-glucan, makes barley unpopular as a feed for swine and poultry. This polysaccharide forms linear chains of β-glucosyl residues polymerized through mixed-(1→3) and (1→4) linkages, which on average consist of 70% (1→4) and 30% (1→3). These linkages are not dispersed randomly throughout the chain, but are arranged such that each (1→3) linkage is separated by one or more (1→4) linkages, causing the chains to become kinked and reducing the overall compaction of the molecule. Combination of the rigid, ribbon-like (1→4) chains with the flexible (1→3) linkages result in chains that are extremely asymmetrical, more water-soluble, and readily form viscous gels (MacGregor and Fincher, 1993; McNab and Smithard, 1992).

Barley endosperm cell walls consist of 75% β-glucans, 20% arabinoxylan, and very small amounts of cellulose, glucomannan, phenolic acids, and protein. Within the starchy endosperm, β-glucan concentrations are very high, whereas low-energy fibrillar and cellulosic materials are present at very low concentrations. Conversely, the hull and other outer layers of barley grain consist of cell wall remnants in which cellulose, silica, and lignin contents are very high, and the β-glucan concentrations are very low. During the germination phase, the cell walls must be completely degraded in order to mobilize starch and other stored nutrients. The scutellum is responsible for synthesizing β-glucanase, which degrades β-glucan in the cell walls.

Protein concentrations in hulled barley range from 8.5 to 21.2% among genotypes with a mean of 13.1%, and can vary by as much as 6.6% within genotypes due to environmental effects (Bhatty, 1993; Torp et al.,1981). Protein concentration of hulless barley also varies widely; however, Jaikaran et al. (1998) reported that hulless barley has a 1 to 2% higher average protein concentration than hulled barley. Despite this large range, protein concentration of feed barley averages 12%, due in part to the extensive use of low-protein malting barley for feed. It has been estimated that with the exclusion of malting barley, protein concentration of feed barley could average close to 15%. Although development of high-protein feed barley has been pursued, efforts to improve quantity of protein in barley have not been very successful due to negative correlation between protein and starch, protein and lysine, and protein and grain yield. Thus, it appears that the potential to increase protein quantity simultaneously with other traits of importance through breeding is very limited (Bhatty, 1993; and Bhatty and Rossnagel, 1981).

The objectives of this study were to: (i) evaluate the agronomic performance and potential of six experimental hulless winter barley lines compared with two commercial hulled cultivars, a commercial triticale cultivar, and a commercial wheat cultivar; (ii) determine and compare fiber, β-glucan, protein, fat, ash concentrations, and TME_n values among these genotypes; and (iii) characterize winter hulless barley accessions from the world collection for use as parents in hulless breeding programs.

MATERIALS AND METHODS

ASSESSMENT OF AGRONOMIC PERFORMANCE AND POTENTIAL

Prior to 1990, winter-barley breeding programs in the United States developed only hulled-barley genotypes and, therefore, adapted winter hulless barley genotypes were not available. The six hulless barley lines evaluated in the current study were developed by Dr. Doyce Graham at Clemson University. These lines were all derived from the cross VA75-42-45/SC793556//CI2457. The first two parents in this cross are hulled winter barley lines developed in Virginia and South Carolina, respectively. Line VA75-42-45 was derived from the cross Jotun /4* Rogers /3/ Cebada Capa / Wong // Awnleted Hudson . Line SC793556 was a reselection from Redhill (CIho 15830). The third parent CI2457 (Lokian) is a hulless winter-habit barley from China. According to Dr. Graham (personal communication), CI2457 was used as a parent for a trait other than the hulless character, perhaps disease resistance. Theoretically, 50% of the genetic composition of the hulless barley lines evaluated in this study was contributed by CI2457, which likely was not well adapted to the mid-Atlantic region. Therefore, performance of these hulless lines compared to hulled commercial cultivars is not expected to be representative of actual differences between hulled and hulless genotypes. Such differences would best be determined through comparisons of hulled versus hulless isogenic lines derived from the same cross.

Six hulless lines from South Carolina, hulled barley cultivars Callao and Starling, triticale cultivar Trical 498, and wheat cultivar Jackson were grown in replicated yield trials at Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland in 1997, 1998, and 1999. The experimental design was a randomized complete block design with four replications. At the four Virginia locations, plots were comprised of seven, 15 cm rows, that were 4 m in length with 30 cm between plots. In February the plots were end-trimmed to a length of 2.75 m. The harvested area was 4.18 m^2. At the two North Carolina locations, plots were seven, 18 cm rows, that were 3 m in length with 30 cm between plots. At the Kentucky location, plots were six, 18 cm rows, that were 3 m in length with 30 cm between plots. At the Maryland location, plots were six, 15 cm rows, that were 4.25 m in length with 30 cm between plots. Planting occurred in late-September to early October, depending on location. Jackson wheat and Trical 498 triticale yield plots were planted as part of a separate test each year at Blacksburg, Orange, Painter, and Warsaw, Virginia.

Plots at each location were fertilized according to soil test recommendations. Specific management practices for each location are presented in Appendix A. Typically, about 56 kg ha^{-1} actual N, P_2O_5, and K_2O, respectively, was applied prior to planting. Approximately 44.8 kg ha^{-1} of 25-0-0-3 (N-P-K-S) was applied between growth stage 25 and 30 (GS 25 and 30) based on Zadoks (1974) decimal code.

Plots were evaluated for heading date, height, and lodging at Blacksburg and Warsaw, Virginia. Lodging was assessed based on the Belgian lodging scale, where area affected is multiplied by the intensity of the lodging, and that product multiplied by 0.2. Area lodged is rated on a scale from 1 (plot unaffected) to 10 (entire plot affected). Intensity is rated on a scale from 1 (plants standing upright) to 5 (plants lying totally flat). For leaf rust a 0 to 9 scale was used to indicate relative disease severity where, 0 = no disease present, and 9 = total plant infection. Height was measured in centimeters, at maturity, and Julian heading date (number of days from 1 January) was recorded.

Plots were harvested with a plot combine between May 24^{th} and June 30^{th} depending on location and year. Samples were weighed, and moisture and test weight calculated using a Dickeyjohn Grain Analysis Computer. Test weights of the hulled barley cultivars were based on a 618 kg m^{-3} standard, while the hulless barley lines, Trical 498 and Jackson wheat were based on 772 kg m^{-3}. Yields of the 10 lines were calculated on a kg ha^{-1} basis for ease of comparison between entries.

Nutrient Analyses

Grain nutrient analyses of Callao, Starling, the six hulless barley lines, Trical 498, and Jackson wheat were conducted to determine TME_n, and the concentrations of fiber, β-glucan, protein, fat, and ash. New Jersey Feed Laboratory, Inc., Trenton, New Jersey, determined the fiber content, while Ingman Laboratories, Inc., Minneapolis, MN determined the β-glucan content. For these analyses, the four replications from each location were combined to form one sample of each entry from each of the seven locations. This produced seven samples of each of the ten entries for a total of 70 samples analyzed each year.

Crude fiber content is measured by boiling an ether-extracted grain sample in dilute acid and dilute base. The sample is then dried, burned, and weighed, the result of which is used to calculate the indigestible portion of the grain (Cheeke, 1991). Desirable fiber content of a feed grain is dependent on the type of animal to which the grain will be fed. Lower fiber concentration is generally preferred in diets of monogastric animals such as poultry and swine. There is an inverse relationship between fiber concentration and energy per unit of feed, thus high fiber content has been an issue of concern in feeding barley-based diets due to lower ME values (Church, 1991).

Beta-glucan content is calculated by determining the percent of glucose molecules linked together by insoluble linkages compared to the total glucose linkages in the grain. Lower concentration of β-glucan is desirable in feed barley due to the negative correlation of poultry and swine performance with increasing β-glucan concentration (MacGregor and Fincher, 1993; McNab and Smithard, 1992).

The University of Georgia, Cooperative Extension Service, College of Agriculture and Environmental Sciences, Athens Georgia conducted a live bird assay with adult roosters to determine the gross energy and TME_n, and protein, fat, and ash concentrations. For this study, grain from each of the four replications was combined at each location, and seed lots from each location were combined into one sample for each entry. This produced a total of ten samples analyzed for TME_n, protein, fat, and ash each year.

TME_n is calculated by feeding adult roosters the feed, determining energy value of excreta with a correction for endogenous nitrogen, and determining gross energy (GE) of feed (Sibbald, 1982). Gross energy is determined by complete oxidation of feed material in a bomb calorimiter. This calculated energy value is inflated compared to ME values calculated from the same feed. However, for purpose of comparison, GE of various feeds may be compared to determine relative ranking order (McDonald, 1995; Cheeke, 1991).

Protein concentrations are determined by multiplying the total nitrogen content by a constant value. This constant varies from grain to grain; however, most nutritionists use the value 6.25 as the standard across grains. This is generally acceptable when comparing protein values of different grains, but not for calculating exact protein concentrations of specific diets. For the purpose of comparing protein concentrations of barley to other grains, the constant 6.25 used by most authors seems reasonable to accept (McDonald et al., 1995; Cheeke, 1991).

Fat content of grain is determined by removal with ether; the resulting change in weight is the percent fat. Fat in animal diets is used as a source of energy containing 2.25 times more digestible energy than carbohydrates. Often, fat is added to rations at a rate of 3 to 5% in order to increase energy. Therefore, any increase in fat content of the grain has the potential to increase energy values such that additional fat is not required (Cheeke, 1991).

EVALUATION OF HULLESS WINTER BARLEY AS AN IMPROVED FEED CROP

Eight hundred and seven winter or facultative habit hulless barley lines were obtained from the USDA-ARS National Small Grains Collection in Aberdeen, ID. Each line was evaluated for disease resistance, starch type, seed color, and agronomic performance. Seedlings of each line were screened in a greenhouse for reaction to races 8 (isolate ND 8702) and 30 (isolate VA90-34) of barley leaf rust (*Puccinia hordei*) and to a composite population of powdery mildew (*Blumeria graminis* f. sp. *hordei*).

For barley leaf rust studies, approximately 20 seeds of each entry in the world collection of hulless barley were planted in plastic pots (75 mm in diameter and 65 mm in depth) filled with a potting mixture (3:1 peat moss/soil). Pots were placed into wooden flats (35 pots per flat), and arranged on a greenhouse bench. Ten to fourteen days after planting (two-leaf stage), seedlings were inoculated with a mixture of urediniospores of *P. hordei* and talc (ca. 1 g of spores per 5 g talc) using an air pump. The inoculated plants were placed in a moist chamber maintained near saturation by intermittent misting from a humidifier for 16 hr at 20 ± 1°C. Following the mist period, the canvas top of the chamber was opened halfway to allow plants to dry slowly. Plants were placed on a greenhouse bench maintained at 22 ± 3°C. Infection types were scored using the 0 to 4 scale of Levine and Cherewick (1952). Readings were performed 10 to 14 days after inoculation. Plants with infection types of 0, 1, and 2 were considered resistant, and plants with infection types 3 and 4 were considered susceptible.

For evaluating powdery mildew, approximately 20 seeds from each entry in the world collection of hulless barley were planted in plastic pots (75mm in diameter and 65 mm in depth) filled with a potting mixture (3:1 peat moss/soil). The pots were placed in wooden flats (35 pots per flat), and arranged on a greenhouse bench maintained at 21 ± 5°C. Inoculum of *B. graminis* f. sp. *hordei* was produced and maintained on seedlings of the susceptible cultivar Dayton. Seedlings were inoculated at the one- to two-leaf stage (10 to12 days after planting). Infected seedlings of Dayton were held about 20 cm over the plant materials and shaken to cause conidia to fall onto the leaves of plants to be inoculated. After 24 hours, the same inoculation procedure was repeated to ensure uniform inoculation. The inoculated plant materials were maintained on the greenhouse bench for an additional 10 to 12 days before evaluation. Each set of plant materials was tested once due to limited availability of seeds.

Reaction type (RT) for powdery mildew was assessed according to the modified scale of Moseman et al. (1984) where 0 = immune, no visible sign of infection; 1 to 3 = resistant, increasing from flecks with no necrosis to large necrotic areas and increasing from no mycelium to few mycelia; 4 to 6 = moderately resistant, necrotic areas changing to chlorotic areas and increasing amount of mycelium and conidiospore production; and 7 to 9 = susceptible, decreasing from chlorotic areas to no chlorosis and increasing amounts of mycelium and conidia production to a completely compatible reaction. From this scale, three major reaction type classes were designated as resistant (RT = 0-3), intermediate (RT = 4-6), and susceptible (RT = 7-9).

Iodine staining of seed was conducted to characterize starch type of each line as starchy (low amylopectin) or waxy (high amylopectin). The iodine staining solution (Berlyn and Miksche, 1976), was comprised of 1g each of iodine and potassium iodide added to 100 ml of water, which was further diluted 1:2 with distilled water to make a working solution (IKI). Three seeds from each line were randomly selected and cut in half. Each half was then dipped in the IKI solution, and the color of endosperm was recorded after 1 minute. The reaction colors were divided into eight shades ranging from dark purple to light pink that indicated starchy and waxy phenotypes, respectively.

Color of seed coat was also recorded, and ranged from dark purple to opaque amber. Color based on a scale of 1 to 8 was categorized as follows: 1) opaque amber; 2) very light brown; 3) light brown; 4) brown; 5) brown and blue/green; 6) blue/green; 7) dark purple; 8) very dark purple.

The hulless lines also were evaluated in a field test. In the fall of 1997 lines were planted in single 1.22 m headrows for agronomic evaluation at Warsaw, Virginia on 22 October. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 89.6, and 134.4 kg ha^{-1}, respectively, on 8 October. On 10 February (GS 25) nitrogen was applied at a rate of 67.2 kg ha^{-1}. On 4 March 1998, octanoic acid ester of bromoxynil (herbicide) was applied at a rate of 38 g ha^{-1}. Nitrogen was applied at a rate of 56 kg ha^{-1} on 25 March (GS 30). On 25 April, 19 g ha^{-1} lambda-cyhalothrin was applied for the control of cereal leaf beetle. Warm temperatures in February caused early growth and cold temperatures in March caused freeze damage. Plots that survived the cold temperatures suffered from severe lodging prior to agronomic evaluations; therefore, only heading date and awn type data could be collected.

In 1998 seed of the world collection of hulless barley, again obtained from the USDA-ARS, was replanted on 20 October in two, 1.22 m headrows, spaced 15 cm apart. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 33.6, and 112 kg ha^{-1}, respectively, on 5 October. On 5 December, 1998 Thifensulfuron and nitrogen were applied at rates of 14.03 g ha^{-1} and 22.4 kg ha^{-1}, respectively, with a boom sprayer. On 1 February 1999, nitrogen was applied at a rate of 22.4 kg ha^{-1}. On 30 March, nitrogen was applied at a rate of 56.0 kg ha^{-1}. On 6 May 1999, 19 g ha^{-1} lambda-cyhalothrin was applied for the control of cereal leaf beetle. Plots were harvested on 4 June 1999. Each line was evaluated for head type (awned, awnless, or hooded), Julian heading date (days from 1 January), and agronomic phenotype.

DATA ANALYSIS

Data from all locations and years were analyzed by analysis of variance using SAS software (SAS Inst., 1999). The general linear model (GLM) procedure was employed (SAS Inst., 1999). Effect of replication, location, line and all interactions were tested. Mean separations were performed by line and/or location if the ANOVA F-statistic indicated significant interaction effects at the 0.05 level (SAS Inst., 1999). Correlation analyses were also run to test for association between yield, test weight, GE, TME and concentrations of fiber, ∃-glucan, protein, fat, and ash.

RESULTS

AGRONOMIC PERFORMANCE

Due to line by location and location by year interactions, results from the agronomic study were analyzed by individual locations within each year. Within locations, entry means comprised of four replications are compared statistically. Means over locations and years are examined; however no statistical inferences can be drawn due to the genotype by environment interactions.

Yield

The hulled barley cultivars Callao and Starling are among the highest yielding cultivars in the region. Since their release, these two cultivars have continued to perform very well in the mid-Atlantic region yield tests.

Mean Yield Over Three Years and Eight Locations

Average yields of Callao (7352 kg ha^{-1}) and Starling (7566 kg ha^{-1}) tended to be higher than those of hulless lines which ranged from 5621 to 6376 kg ha^{-1} (Fig. 3). Average yield of all hulless lines was 81% of that of hulled cultivars. However, the average yield of SC890573 (6376 kg ha^{-1}) was 87% of that of Callao, and 75 and 76% of that of Trical 498 (8450 kg ha^{-1}) and Jackson (8433 kg ha^{-1}), respectively.

Both Callao and Starling yielded significantly (P#0.05) higher than all hulless lines at Blacksburg, Orange, Warsaw, Kinston, Lexington, and Keedysville in 1997; and at Warsaw in 1998 (Tables 1 and 3). At the other locations in 1997 and 1998, there also was a trend toward higher yield for hulled cultivars compared to hulless lines. In 1999, yields of hulled cultivars tended to be similar or lower in magnitude than those of hulless lines due to hot dry conditions during the grain-fill period (Table 5).

There were no consistently high-yielding hulless lines in 1997 over locations. Each hulless line was the highest yielding at least once across the eight locations. In 1998 and 1999, five of the six hulless lines were the highest yielding at least once across the eight locations. Averaged across locations, SC 890573 was the highest yielding line in 1997 and 1999, while SC890585 was the highest yielding line in 1998. Averaged over years, SC890573 was the highest yielding line, followed by SC890585, SC860934, SC880248, SC860972, and SC860974, respectively. Each of the three years, SC860972 and SC860974 ranked fifth and sixth, respectively, in yield.

1997

Although not statistically valid, average yield comparisons across locations provide a basis of relative performance. Average yields of Callao and Starling tended to be higher than those of hulless lines (Fig. 4). The highest yielding hulless line, SC890573, yielded 11% higher than that of the lowest yielding hulless line, SC860974 (Table 1). Yield of SC890573 was 67% of that of Callao, while average hulless yields were 63% that of average hulled yields.

In 1997 at Blacksburg, Orange, and Warsaw Virginia; Lexington, Kentucky; and Keedysville, Maryland yields of Callao and Starling were significantly higher (P#0.05) than those of hulless lines (Table 1). At Painter, Virginia, yield of Starling was significantly higher (P#0.05) than those of hulless lines except SC890573. Yields of hulless lines ranged from 9088 to 7282 kg ha^{-1}, which were not different significantly (P >0.05) from that of Callao. At Kinston, North Carolina, Callao yielded significantly more (P#0.05) than did hulless lines with the exception of SC880248 and SC890585, while yield of Starling did not differ significantly (P > 0.05) from those of the hulless lines. At Rowan, North Carolina, yields of Callao and Starling did not differ significantly (P > 0.05) from yields of hulless lines. There was a trend toward higher yields from hulled barley compared to hulless barley; however, large amounts of variation between replications caused a coefficient of variation of 32%, resulting in no significant difference.

In 1997, yield among hulless lines did not differ significantly (P > 0.05), nor did yield of Callao and Starling significantly differ (P > 0.05) at any location. However, there were significant differences (P#0.05) in yield between the hulless lines and the hulled cultivars of barley. Trical 498 yielded more than Jackson at Blacksburg and Warsaw, while similar yields were obtained at Orange and Painter Virginia (Table 2). Average hulless yield for 1997 was 55% of that of Trical 498 and 67% of that of Jackson. Average yield of SC890573 was 58% of Trical 498 and 71% of Jackson. Painter, Virginia had the highest average yield for hulled and hulless barley, and triticale and wheat in 1997 (Tables 1 and 2, respectively).

<u>1998</u>

Average yields of Callao and Starling tended to be slightly higher than those of hulless lines (Fig. 5). The highest yielding hulless line, SC890585, yielded 26% higher than the lowest yielding hulless line, SC860974 (Table 3). Yield of SC890585 was 97% of that of Callao, while average hulless yield was 82% that of average hulled yield.

In 1998 at Blacksburg, Virginia, there were significant differences in yield (P#0.05) between hulless lines (Table 3). Starling had a significantly higher yield (P#0.05) than hulless lines except SC890585, and Callao had significantly higher (P#0.05) yield than hulless lines except for SC890585 and SC890573. At Orange, Virginia, there were significant differences (P#0.05) in yields between hulless lines, and yield of Starling was significantly higher (P#0.05) than those of hulless lines except SC880248. Yield of Callao was significantly higher (P#0.05) than those of hulless lines except SC890585 and SC890573. At Painter, Virginia, yields of Callao and Starling were significantly different (P#0.05). Yield of Starling was significantly higher (P#0.05) than those of hulless lines SC860972, SC860974, and SC880248. Yield of Callao did not differ significantly (P > 0.05) from those of hulless lines. At Warsaw, Virginia, yields of Callao and Starling were significantly higher (P#0.05) than those of hulless lines. There also were significant differences in yields (P#0.05) between hulless lines. At Kinston, North Carolina, yield of Starling was significantly higher (P#0.05) than that of hulless lines except SC860972, SC880248, and SC890585, while yield of Callao was significantly higher (P#0.05) than that of the hulless line SC860974. At Rowan, North Carolina, yields of Callao and Starling did not differ significantly (P > 0.05) from those of hulless lines. At Lexington, Kentucky, yields of SC890585 and SC890573 were significantly higher (P#0.05) than those of any other entry, hulled or hulless. Yield of Starling was significantly higher (P#0.05) than that of SC860934, SC860972, and SC880248. Callao had significantly lower (P#0.05) yield than any other entry. At Keedysville, Maryland, yields of Callao and Starling did not differ significantly (P > 0.05) from those of hulless lines SC860934, and SC890585, while yield of Callao was significantly higher (P#0.05) than that of the hulless line SC860974.

Yield of Trical 498 was significantly (P#0.05) lower than that of Jackson at Orange. At Blacksburg, Painter, and Warsaw yields of Trical 498 and Jackson were similar (Table 4). The reduced yield of Trical 498 observed in 1998 compared to 1997 was due to a spring freeze that damaged the crop. Average hulless yield was 85 and 70% that of Trical 498 and Jackson, respectively. Average yield of SC890585 was 95 and 78% that of Trical 498 and Jackson, respectively.

In 1998, yields of hulless lines significantly differed (P#0.05) from each other at Blacksburg, Painter, Warsaw, and Lexington, while the yields of Callao and Starling differed significantly (P#0.05) only at Painter and Lexington. There were also significant differences (P#0.05) in yields between hulless lines and hulled cultivars of barley. Warsaw, Virginia had the highest average yield for hulled and hulless barley in 1998 (Tables 3), while Orange, Virginia had the highest average yield for triticale and wheat in 1998 (Table 4).

<u>1999</u>

Average yields of Callao and Starling were similar to those of hulless lines (Fig. 6). The highest yielding hulless line, SC890573, yielded 2.5% higher than the lowest yielding hulless line, SC880248 (Table 5). Yield of SC890573 was 109% of that of Callao, while average hulless yields were 104% that of average hulled yields.

Yields of Callao and Starling in 1999 at Blacksburg, Orange, Painter, and Warsaw, Virginia; and Kinston and Rowan, North Carolina were not significantly different ($P > 0.05$) from those of hulless lines (Table 5). At the same locations, there were no significant differences ($P > 0.05$) among the hulless lines. At Lexington, Kentucky, yield of Starling was significantly higher than those of all hulless lines except SC880248 and SC890573. Yield of Callao at Lexington did not differ significantly ($P > 0.05$) from those of the hulless lines. At Keedysville, Maryland, yield of Callao was significantly higher than that of hulless line SC860934, while yield of Starling did not differ ($P > 0.05$) from those of hulless lines.

Yield of Trical 498 was higher than that of Jackson at Blacksburg, while Jackson had a higher yield than Trical 498 at Orange, Painter, and Warsaw (Table 6). Average yield of hulless lines was 83 and 78% of that of Trical 498 and Jackson, respectively. Average yield of SC890573 was 87 and 83% that of Trical 498 and Jackson, respectively.

In 1999, yield among hulless lines differed significantly (P#0.05) only at Lexington, Kentucky. There were also significant differences (P#0.05) in yield between hulless lines and hulled cultivars of barley at Lexington, Kentucky, and Keedysville, Maryland. Blacksburg, Virginia had the highest average yield for hulled and hulless barley, and triticale and wheat in 1999 (Tables 5 and 6, respectively).

Test Weight

The standard test weight of hulled barley is 618 kg m^{-3}. Callao has a very high test weight and averages 650 kg m^{-3}, while Starling has an average test weight very close to 618 kg m^{-3}. However, these test weights are considerably lower than the average test weight of 772 kg m^{-3} for wheat.

Mean Test Weights Over Three Years and Eight Locations

Three-year average test weights of Callao (652 kg m^{-3}) and Starling (620 kg m^{-3}) tended to be lower than those of hulless lines, which ranged from 702 to 736 kg m^{-3} (Fig.

7). Average test weight of hulless lines was 13% higher than that of hulled cultivars. The average test weight of SC860974 (736 kg m^{-3}) was 13 and 15% higher than that of Callao and Trical 498 (638 kg m^{-3}), respectively, and 98% of that of Jackson (755 kg m^{-3}).

Over years, hulless lines and Jackson had similar test weights that tended to be higher than those of hulled barley and Trical 498. The exception was in 1999 where test weights of hulled barley were similar to those of hulless barley due to hot, dry conditions during the grain-fill period. However, these conditions are not typical of the mid-Atlantic region, and average data indicated a trend toward higher test weight of hulless barley compared to that of hulled barley and triticale.

1997

Average test weights of Callao and Starling over locations tended to be lower than those of hulless lines in 1997 (Fig. 8). Average test weight of hulless lines was 19% higher than that of hulled cultivars. The average test weight of SC890585 was 17% higher than that of Callao.

In 1997 at Blacksburg, Virginia, test weights of Callao and Starling did not differ significantly (Table 7). Test weight of Callao was not significantly different ($P > 0.05$) from those of SC860934 and SC860972. However, test weights of the remaining four hulless lines were significantly higher (P#0.05) than those of the two hulled barley cultivars. At Orange, Painter, and Warsaw, Virginia; Lexington, Kentucky; and Keedysville, Maryland, test weights of hulless lines were significantly higher (P#0.05) than those of hulled barley cultivars Callao and Starling. At Warsaw, Virginia, and Lexington, Kentucky, test weight of Callao was significantly higher than that of Starling. At Kinston, North Carolina, test weight of Callao did not differ significantly from that of Starling or SC860972. However, test weight of Starling was significantly lower (P#0.05) than those of the hulless lines, and test weight of Callao was significantly (P#0.05) lower than those of all hulless lines except SC860972. At Rowan, North Carolina, test weight of Callao did not differ significantly ($P > 0.05$) from that of Starling or those of hulless lines.

Test weight of Trical 498 was significantly (P#0.05) lower than that of Jackson at Blacksburg, Orange, Painter, and Warsaw, Virginia (Table 8). Average test weight of hulless lines was 7% higher than that of Trical 498, and 94% that of Jackson. Average test weight of SC890585 was 9% higher than that of Trical 498, and 95% that of Jackson. Warsaw, Virginia had the highest average test weight for hulled and hulless barley in 1997 (Table 7), while Orange, Virginia had the highest average test weight for triticale and wheat in 1997 (Table 8).

1998

Over locations, average test weights of Callao and Starling tended to be lower than those of hulless lines (Fig. 9). Average test weight of hulless lines was 23% higher than that of hulled cultivars. The average test weight of SC860974 was 21 and 30% higher than that of Callao and Starling, respectively.

Test weights of hulless lines were significantly higher than those of Callao and Starling in 1998 at Blacksburg, Painter, and Warsaw, Virginia; Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland (Table 9). At Warsaw, Virginia, and Kinston, North Carolina, test weight of Callao did not differ significantly from that of Starling. Test weight of Callao at Kinston, North Carolina was not significantly different ($P > 0.05$) from those of hulless lines, and test weight of Starling did not differ significantly ($P > 0.05$) from hulless lines SC860934 and SC890573. At Orange, Virginia, no test weight was recorded.

Test weight of Trical 498 was significantly (P#0.05) lower than that of Jackson at Blacksburg , Orange, Painter, and Warsaw, Virginia (Table 10). Average test weight for hulless lines was 22% higher than that of Trical 498, and 94% that of Jackson. Average test weight of SC860974 was 25% higher than that of Trical 498, and over 99% that of Jackson. Warsaw, Virginia and Rowan, North Carolina had the highest average test weight for hulled and hulless barley in 1998 (Table 9), while Orange, Virginia had the highest average test weight for triticale and wheat in 1998 (Table 10).

1999

Test weights of Callao and Starling were not significantly different (P > 0.05) from those of hulless lines at any location in 1999 (Fig. 10) (Table 11). At Painter, Virginia, the test weight of Callao was significantly higher (P#0.05) than hulless line SC860934, while test weight of Starling did not differ significantly (P > 0.05) from those of hulless lines.

Test weight of Trical 498 was significantly (P#0.05) lower than that of Jackson at Blacksburg, Orange, Painter, and Warsaw (Table 12). Average test weight for hulless lines was 12% higher than that of Trical 498, and 95% that of Jackson. Average test weight of SC860974 was 15% higher than that of Trical 498, and 99% that of Jackson. Kinston, North Carolina had the highest average test weight for hulled and hulless barley in 1999 (Table 11), while Blacksburg and Orange, Virginia had the highest average test weight for triticale and wheat in 1999 (Table 12).

Heading Date

Callao is an early-heading barley, which heads at approximately 108 days in the mid-Atlantic region. Starling is a moderately late-heading barley, heading at approximately 113 days.

Overall

Over years at Blacksburg, Callao was the earliest heading barley at 114 days, followed by SC890585 at 116 days (Table 13). At Warsaw, Callao and SC890585 were the earliest heading at 102 days. Starling was the latest heading at Warsaw (107 days), while at Blacksburg SC860972 and SC860974 (119 and 120 days, respectively) were the latest heading. Trical 498 tended to have an earlier heading date than Jackson (115 versus 125 days) (Table 14).

1997

In 1997 at Blacksburg, Virginia, heading date of Callao was significantly earlier (P#0.05) than those of other entries (Table 15). Starling heading date was not significantly different ($P > 0.05$) from the latest heading hulless lines. At Warsaw, four hulless lines had heading dates similar to that of Callao. Heading date of hulless lines ranged from 101 to 105 days, while heading date of Starling was significantly later than any other entry. Average heading date of Trical 498 and Jackson wheat was 118 and 130 days, respectively (Table 16). Average heading date of hulless lines was 5 and 16 days earlier than Trical 498 and Jackson, respectively.

<u>1998</u>

At Blacksburg in 1998, heading date of Callao was significantly earlier (P#0.05) than that of any other entry (Table 17). Heading date of Starling did not differ significantly ($P > 0.05$) from that of the latest heading hulless lines. At Warsaw, two hulless lines had heading dates that did not differ from that of Callao. Heading date of hulless lines ranged from 101 to 108 days. Heading date of Starling did not differ significantly ($P > 0.05$) from the latest heading hulless line. Trical 498 and Jackson had average heading dates of 114 and 118 days, respectively (Table 18). Average heading date of hulless lines was 6 and 10 days earlier than Trical 498 and Jackson, respectively.

<u>1999</u>

Heading date in 1999 of Callao and Starling at Blacksburg did not differ significantly from that of any other entry (Table 19). Hulless lines ranged in heading date from 114 to 117 days, with SC890585 heading earlier than SC860974. At Warsaw, heading date of Callao and Starling was not significantly different ($P > 0.05$) from that of any other entry. Heading dates of hulless lines did not differ significantly ($P > 0.05$) from each other. Average heading dates of Trical 498 and Jackson were 120 and 131 days, respectively (Table 20). Average heading date of hulless lines was 2 and 15 days earlier than Trical 498 and Jackson, respectively.

Plant Height

Callao, a very short barley, has an average plant height of 90 cm, while Starling, a moderately tall barley, has an average plant height of 101 cm.

Overall

Over years, Callao had the shortest plant height at Blacksburg and Warsaw, respectively (Table 13). The shortest hulless line was SC890585, which averaged 95 and 94 cm at Blacksburg and Warsaw, respectively. At Blacksburg, SC860934 had the tallest plant height, while at Warsaw, SC860974 and Starling had the tallest plant height. Trical 498 tended to have a taller average plant height than Jackson at Blacksburg, and Warsaw (Table 14).

1997

At Blacksburg, height of Callao was significantly (P#0.05) lower than that of Starling (Table 15). Height of hulless lines ranged from 87 to 100 cm, and did not differ significantly ($P > 0.05$) from that of Callao. At Warsaw, height of Callao also was significantly lower (P#0.05) than that of Starling. Height of hulless lines ranged from 91 to 105 cm. Height of Callao was significantly lower (P#0.05) than that of SC860934, SC860972 and SC860974, while height of Starling was significantly higher (P#0.05) than that of all other entries except SC860934. Average height of Trical 498 and Jackson was 124 and 96 cm, respectively (Table 16).

1998

Plant height of Callao at Blacksburg was significantly lower (P#0.05) than that of any other entry (Table 17). Height of hulless lines ranged from 96 to 110 cm. Height of SC860972 was significantly lower (P#0.05) than that of SC860934, while height of Starling did not differ significantly from that of hulless lines. At Warsaw, height of Callao was significantly lower (P#0.05) than that of Starling and hulless lines, which ranged from 93 to 104 cm. Height of Starling did not differ significantly ($P > 0.05$) from that of hulless lines. Average height of Trical 498 and Jackson was 106 and 94 cm, respectively (Table 18).

1999

At Blacksburg, heights of Callao and Starling did not differ from those of hulless lines which ranged from 90 to 100 cm (Table 19). At Warsaw, heights of Callao and Starling did not differ from those of hulless lines, which ranged from 94 to 100 cm. Trical 498 and Jackson had average heights of 101 and 96 cm, respectively (Table 20).

Lodging

Callao is a moderately-weak strawed cultivar that is susceptible to lodging. Starling is a moderately-strong strawed barley and tends to resist lodging.

Overall

Lodging scores averaged over the three years were highest for Callao, Starling, SC860972, and SC860974 at Blacksburg (Table 13). Average lodging scores of SC860934, SC880248, SC890573, and SC890585 were the lowest. At Warsaw average lodging scores were highest for Callao, SC860972, and SC860974. Starling, SC860934, SC880248, SC890573, and SC890585 had the lowest lodging scores at Warsaw. Average lodging scores for Trical 498 and Jackson were 3.8 and 7.4, respectively. Trical 498 and Jackson both had scores of 1.6 at Warsaw (Table 14).

1997

At Blacksburg, lodging scores of Callao and Starling did not differ from those of hulless lines (Table 15). Lodging scores of hulless lines ranged from 0.2 to 0.4. At Warsaw lodging scores of Callao, SC860934, SC860972, and SC860974 were higher than those of any other entry. SC890585 had the lowest lodging score which did not differ from Starling, SC880248, and SC890573. No lodging was observed in plots of Trical 498 and Jackson in the state wheat test in 1997 (Table 16).

1998

At Blacksburg, lodging scores of Callao and Starling differed significantly (P#0.05), as did those of hulless lines (Table 17). Lodging scores of SC860972 and SC860974 were significantly higher than those of any other hulless entry and did not differ from that of Callao. Hulless lines SC880248, SC890573, and SC890585 had lodging scores lower than those of Callao. At Warsaw, lodging scores of Callao and SC860974 were significantly higher than those of SC880248, SC890573, and SC890585, while lodging of Starling did not differ ($P > 0.05$) from that of any other entry. Lodging score for Trical 498 was lower than that of Jackson at Blacksburg (Table 18), while at Warsaw, Trical 498 had a higher lodging score than that of Jackson due to spring freeze damage.

1999

At Blacksburg, lodging scores of Callao and Starling did not differ from those of hulless lines, which ranged from 0.4 (SC880248) to 7.5 (SC860974) (Table 19). At Warsaw, no lodging was observed. Average lodging scores for Trical 498 and Jackson were 0.2 and 2.3, respectively, at Blacksburg (Table 20).

NUTRIENT ANALYSES

Data for fiber and β-glucan concentrations were analyzed across locations and years due to the absence of genotype by environmental interaction. Therefore individual locations were not compared, but rather means of lines over locations within years, and over years are compared and discussed for both fiber and β-glucan. Data for protein, fat, and ash concentration, and gross energy values within each year are based on single determinations. Therefore statistical analyses could not be performed on the data for each year; however, data were analyzed across years. Data for TME_n was statistically analyzed for each year and across years.

Fiber Concentration

Analysis of the 1997 grain samples indicated that Starling had the highest (P >0.05) concentration of fiber, followed by Callao (Table 21). The hulless lines, which ranged from 1.96 to 2.64%, had significantly lower (P > 0.05) fiber concentrations than the hulled barley. Trical 498 and Jackson had higher (P< 0.05) fiber concentrations than all hulless lines except for SC860972. Fiber concentrations in 1998 were again significantly higher (P#0.05) for Starling and Callao than the other entries, and Starling had a significantly higher (P#0.05) fiber concentration than Callao. Jackson and Trical 498 had significantly lower concentrations of fiber than Starling or Callao, but were higher in fiber concentration than the hulless lines. In 1999, Starling once again had the highest (P#0.05) concentration of fiber, and was significantly higher (P#0.05) than that of Callao. Trical 498 had a significantly higher (P#0.05) concentration of fiber than Jackson. The hulless lines had the lowest fiber concentrations, which ranged from 1.64 to 1.94%.

Over years, fiber concentration of Starling was significantly (P#0.05) higher than that of any other entry, while Callao fiber concentration was significantly higher than that of Trical 498, Jackson, and the hulless lines. Within years and over years, hulless lines had significantly (P#0.05) lower fiber concentrations than Trical 498 and Jackson.

β-glucan Concentration

In 1997, Jackson and Trical 498 had lower (P#0.05) concentrations of β-glucan than hulled or hulless barley (Table 21). Callao and Starling had β-glucan concentrations of 5.67 and 4.89%, respectively, while β-glucan concentrations of the hulless lines ranged from 4.73 to 6.13%. Jackson and Trical 498 had significantly lower β-glucan concentrations in 1998 than hulled or hulless barley. Callao and Starling had β-glucan concentrations of 3.99 and 3.61%, respectively, while concentrations of hulless lines ranged from 3.05 to 4.39%. In 1999, Jackson and Trical 498 once again had significantly lower (P#0.05) concentrations of β-glucan, than hulled or hulless barley. Beta-glucan concentrations of hulless barley ranged from 3.51 to 4.53%, respectively.

Average β-glucan concentration over years was higher for Callao than for SC860972, SC860974, and SC890573 (Table 21). Average β-glucan concentration of Starling was lower than that of SC880248. Trical 498 and Jackson β-glucan concentrations were significantly (P#0.05) lower than those of hulled or hulless barley.

Protein Concentration

Protein concentrations of Callao and Starling were lower than those of any other entry in 1997 (Table 22). Jackson had the highest protein concentration (11.84%), while protein of hulless lines ranged from 10.67 to 11.67%. In 1998, protein concentrations of hulless lines ranged from 11.63 to 13.19% (Table 23). Protein concentrations of Callao, Starling, Trical 498, and Jackson tended to be lower and ranged from 11.46 to 11.75%. Jackson had the highest protein concentration (14.33%) in 1999 and Callao had the lowest protein concentration (9.80%) (Table 24). Hulless lines ranged from 10.23 to 11.75% in protein concentration.

Average protein concentrations over years did not differ among the hulless lines, nor did hulless lines differ from hulled barley, Trical 498, or Jackson (Table 25). Hulless barley protein concentrations ranged from 10.95 to 11.94%. Callao and Starling both had protein concentrations of 10.45%, and Trical 498 had a concentration of 11.18%. The average protein concentration of Jackson was 2.12% higher than that of Callao and Starling. However, it is important to note that triticale and wheat plots generally received higher rates of spring nitrogen than barley plots, which may explain part of the difference in protein concentrations of Jackson versus hulled and hulless barley.

Fat Concentration

In 1997 and 1999, the range in fat concentrations of hulless lines encompassed the high and low extremes of all entries (Tables 22 and 24, respectively). In 1998, however, Jackson had a lower fat concentration than that of the lowest hulless line, while Callao tended to have a higher concentration than that of the highest hulless line (Table 23).

Over years and locations, Callao and Starling had mean fat concentrations of 1.59 and 1.33%, respectively, while hulless lines ranged from 1.19 to 1.59% (Table 25). Trical 498 and Jackson had fat concentrations of 1.47 and 1.27%, respectively. Callao had a higher fat concentration than SC860974, SC880248, and Jackson. Fat concentration of Starling did not differ from that of any other entry. SC880248 had a lower fat concentration than Callao, SC860934, SC860972, SC SC890573, SC890585, and Trical 498. Fat concentration was lowest for SC880248, while Callao maintained a higher average fat concentration similar to those of the highest hulless lines (Table 25). The average fat concentration of Starling tended to be most similar to those of the lower hulless lines.

Ash Concentration

Ash concentration of SC890573 was 42 to 72% higher in magnitude than that of any other entry in 1997 (Table 22), while in 1998 (Table 23), ash concentration was highest for Starling. In 1999 Callao had the highest ash concentration (Table 24).

Overall, mean ash concentrations for Callao and Starling were 1.93 and 2.06%, respectively (Table 25). Hulless lines had ash concentrations ranging from 1.69 to 2.05% (Table 17). Jackson and Trical 498 had ash concentrations of 1.84 and 1.53%, respectively. Ash concentration of Jackson was significantly lower ($P < 0.05$) than that of Starling and SC890573. Among hulled and hulless barley and Trical 498 there were no significant ($P > 0.05$) differences in ash concentration.

Gross Energy

Gross energy values of Callao and Starling were similar in magnitude to those of hulless lines, Trical 498, and Jackson in all three years (Table 22, 23 and 24).

Over years, gross energy values for Trical 498 were significantly lower ($P < 0.05$) than those of Callao, SC860972, SC860974, and SC880248 (Table 25). With the exception of Trical 498, entries did not differ significantly (P>0.05) from each other for gross energy.

True Metabolizable Energy

In 1997, SC880248 had a significantly higher TME_n value than those of Starling, SC860974, SC890573, SC890585, and Jackson (Table 22). However in 1998, Jackson had the highest TME_n value, which was significantly higher than those of Callao, Starling, SC860934, and SC860974 (Table 23). In 1999, TME_n values were similar for all entries, except that of SC890585, which was significantly higher than that of Callao (Table 24).

Over years, TME_n values did not differ significantly (P>0.05) among the ten entries (Table 25). TME_n of Callao and Starling tended to be lower than that of the hulless lines and Trical 498 and Jackson.

CORRELATION

No significant correlations were observed between grain yield, test weight, GE, TME, and concentrations of fiber, ∃-glucan, protein, fat, and ash utilizing Proc. Corr. (SAS, 1999) (Table 26).

WORLD COLLECTION OF HULLESS WINTER BARLEY

Of the 807 winter hulless barley lines evaluated from the world collection, approximately 23.5% exhibited some resistance to powdery mildew (Table A-2). Approximately 3.5 and 5.8% exhibited some resistance to races 8 and 30, respectively, of barley leaf rust. Although seed color of feed barley is not of primary concern, it is an important component of food barley. Approximately 9% of the 807 lines had light brown/amber seed color and plump, heavy kernels similar to wheat. The majority of lines (802 of 807) were of the starchy phenotype. Heading date was normally distributed. Head type was categorized as smooth (3.2%), short awned (33.0%), long awned (61.1%), or hooded (2.7%). Many lines were excessively tall, had weak straw, and were of an undesirable phenotype.

Of the 807 lines evaluated, approximately 80 exhibited favorable phenotypes in the environment tested (Table 27). These lines were selected for more thorough examination and use as potential parents in the future. The eighty lines selected originated from nine countries. One line each was selected from Afghanistan, Bulgaria and Nepal. Three and four percent of the lines selected originated in Switzerland and the USA, respectively. Ten percent of the lines were selected from both Korea and India, while 11% originate in China. The remaining 51% were of Japanese origin. The majority (99%) of these selected lines were of starchy phenotype. Seed color ranged from opaque amber (28%) to dark purple (3%) with the remainder having seeds of brow/blue color. Barley leaf rust resistance to race 8 was present in 19% of the lines, while resistance to race 30 was present in only 10% of the lines. Twenty eight percent of the lines selected possessed some level of resistance to powdery mildew. Awn length was primarily short (53%) or long (43%), while one line selected was awnless and the remainder were hooded. Heading date was normally distributed, and ranged from 93 to 119 days, with 63% of the lines heading between 102 and 107 days. Twenty percent of the lines headed before day 102 and 17% headed after day 107.

DISCUSSION

AGRONOMIC TRAITS

Yield and Test Weight

Hulled barley cultivars, Callao and Starling, had 59 and 22% higher average yields than the six hulless lines in 1997 and 1998, respectively, but had lower test weights (Tables 1 and 3). Across the state of Virginia, record barley yields and test weights were reported in 1999. Under these favorable conditions no difference was observed in yield or test weight between hulled cultivars and hulless lines, a phenomenon perhaps attributed to the extended period of hot, dry weather during the grain-fill period. These conditions tended to promote higher test weights in barley, although hulled barley exhibited a more dramatic increase in test weight than hulless barley compared to other years. In contrast, yields of hulless lines tended to be elevated compared to those of hulled cultivars in 1999 giving rise to a more homogeneous yield and test weight of hulled versus hulless barley. Over years, yields of hulled barley were approximately 1000 kg ha^{-1} higher than those of hulless lines, while test weights of hulled cultivars were approximately 80 kg m^{-3} lower than those of hulless lines (Tables 2, 4 and 6). Reduced yields have been commonly observed in spring hulless barley (Bhatty, 1993). Rossnagel et al. (1981) reported that spring hulless barley varieties yielded an average of only 88% of that of hulled check varieties. In the current study, mean yield of the best hulless line SC890573 was 87 and 84% of that of Callao and Starling, respectively. Due to the lack of extensive breeding effort for increased yield in these hulless lines, it is probable that yields of hulless winter barley in the mid-Atlantic region can surpass 88% of that of hulled barley. However, it is important to note that yield of hulless barley potentially equals 87 to 90% of that of hulled barley. This is due to the weight of the hulls, which account for 10 to 13% of the weight of hulled barley.

Since barley is a winter annual in the mid-Atlantic region, its performance is more consistent than that of corn. Corn tends to be subject to drought stress in the mid and latter part of the growing season. Barley also allows for a double-crop system with soybeans, which are more drought-stress tolerant than corn. Therefore, barley and soybeans provide an economical alternative to raising corn in the mid-Atlantic region.

In 1997, yields of Trical 498 and Jackson were 98 and 81% that of Callao and Starling, respectively, (Table 1). Yields of Trical 498 and Jackson, respectively, were 52 and 25% higher than the average yield of hulless barley cultivars. In 1998, yield of Trical 498 was 12% lower than that of hulless lines. Hulled cultivars yielded 24% more than hulless lines, while yield of Jackson was 9% higher than that of the hulless lines. In 1999, yields of Trical 498 and Jackson were respectively 5 and 11% higher than those of hulless barley. Overall, yields of Trical 498 and Jackson were both 15% higher than those of hulless barley. Test weight of hulled barley was most similar to that of Trical 498, while test weights of the hulless lines were most similar to that of Jackson.

Heading Date, Plant Height, and Lodging

Callao is a early heading, short statured, weak strawed, high test weight barley. Starling is a late maturing, standard height, moderately stiff-strawed, low to average test weight barley. The hulless lines varied within the range of the hulled cultivars for heading date, height, and lodging. There was a trend toward an earlier heading date for Callao over years, while heading date of Starling tended to be later than other entries. Heading dates of the six hulless lines varied over a range of dates that tended to be in between Callao and Starling. Plant height tended to be lower for Callao, while Starling tended to have one of the highest plant heights of the entries. Hulless lines generally ranged slightly taller than Callao to slightly shorter than Starling. Starling tended to resist lodging to a greater degree than Callao. Hulless lines varied in lodging with some being similar or better than Starling and others similar to Callao.

NUTRIENT ANALYSES

Fiber

Fiber concentration ranged from 4.52 to 5.05% for hulled barley and 1.8 to 2.17% for hulless barley with respective averages of 4.79 and 2.00%. Average fiber concentrations for Trical 498 and Jackson (2.64 and 2.41%, respectively) were slightly higher than that of the hulless lines. These values are very close to results of other studies which reported fiber concentrations averaging 1.8% for hulless barley and 5.4% for hulled barley (Bhatty and Rossnagel, 1981; Jeroch and Danicke, 1995; Bhatty et al., 1979). Published nutrition tables report average fiber values of 2.2 and 5.2% for hulless and hulled barley, respectively (Church, 1991; Jurgens, 1988).

Lower fiber concentrations of hulless barley allow formulation of a ration that contains more energy per unit, compared to a ration formulated with hulled barley. Traditionally, wheat has been an excellent choice compared to hulled barley when fiber is an issue of concern. Therefore, hulless barley has great potential due to fiber concentrations similar to that of wheat.

β-glucan

Mean β-glucan concentrations for Callao and Starling were 4.70 and 4.25%, respectively, and ranged from 3.77 to 4.94 % among hulless lines. The β-glucan concentrations determined in this study are in agreement with other published values which range from 2.8 to 7.8%. Average values of 5.40 and 4.92% have been reported for hulled and hulless barley, respectively (Zhi-Yuan et al., 1995; Jeroch and Danicke, 1995; Newman and Newman, 1988; and Rotter et al. 1990). Mean β-glucan concentrations for Trical 498 and Jackson (0.64 and 0.65%, respectively) were significantly lower than those of barley. Grains with very low concentrations of β-glucan are desirable in the diets of monogastric animals to avoid associated complications. With the addition of β-glucanase to hulless barley diets, the effects of β-glucan are negated, which allows hulless barley to be considered as a viable component in the diets of poultry and swine. However, when grain is fed shortly after harvest, without sufficient aging, β-glucan content is high and the amount of supplemental enzyme added should be considered.

In the current study, a 19% increase in β-glucan concentration was observed from 1998 to 1999. The weather conditions during grain-fill in 1998 were cool and wet, while in 1999 conditions during grain-fill were hot and dry. This finding is supported by

Bhatty (1993) who reports that extended periods of hot dry weather prior to harvest have been found to greatly increase β-glucan concentrations.

Protein Concentration

Mean protein concentrations for hulless barley in this study ranged from 10.95 to 11.94% with an average of 11.33%, while hulled barley protein concentrations were 10.45% for both varieties. These values are close to those reported by Jaikaran et al. (1988) where hulless barley had 1 to 2% higher protein concentration than hulled barley on average. Church (1991) and Jurgens (1988) cited average protein concentrations of 10.35 and 11.15 % for hulled and hulless barley, respectively, which are very close to the values reported in the present study. However, a mean protein concentration of 13.6 and 15.6% for hulled and hulless barley, respectively, was calculated from several other experiments (Zhi-Yuan et al., 1995; Bhatty and Rossnagel, 1981; Bhatty et al., 1979, 1975; Jeroch and Danicke, 1995; Newman and Newman, 1988).

Higher protein concentrations in the current study of hulless lines compared to hulled cultivars is important. Higher protein content of the grain provides a more nutritious feed, which enhances animal performance. The feed is also less costly since high value additives can be reduced.

Fat Concentration

Fat concentration in the current study ranged from 1.19 to 1.59%, and no differences were observed among hulled and hulless barley, Trical 498, or Jackson. These values differ considerably from those reported by Jeroch and Danicke (1995). They reported fat concentrations of 2.9 and 3.2% for hulled barley and 2.1% for hulless barley. Hulless lines had a range in fat concentration of 1.19 to 1.59% in the current study, and it seems probable that with selection, fat content could be increased. Increased fat concentration theoretically would result in increased energy value of the barley. Thus, a grain with higher energy and less need for costly supplements would prove to be beneficial to the poultry and swine industries.

Ash Concentration

Ash values averaged 2.00 and 1.77% for hulled and hulless barley, respectively. In nutritional tables, Church (1991) and Jurgens (1988) cited ash values of 2.4 and 1.8%, respectively, for hulled and hulless barley. These values are also very close to reported experimental averages of 2.5 and 1.9% for hulled and hulless barley, (Zhi-Yuan et al., 1995; Bhatty and Rossnagel, 1981; Bhatty et al., 1979, 1975; Jeroch and Danicke, 1995; Newman and Newman, 1988).

Gross Energy

Gross energy values ranged from 3891 to 3903 kcal kg^{-1} in hulled barley and 3877 to 3903 kcal kg^{-1} in hulless barley with averages of 3898 and 3889 kcal kg^{-1}, respectively. Gross energy values of Trical 498 and Jackson were 3846 and 3877 kcal kg^{-1}, respectively. These values for barley are lower than those reported by Bhatty et al. (1979, 1975), where GE of hulled and hulless barley ranged from 4228 to 4735 kcal kg^{-1} and 4154 to 4699 kcal kg^{-1}, respectively, and averaged 4491 and 4474 kcal kg^{-1}, respectively. However, GE values of the current study are slightly higher than those reported in nutrition tables and for hulled (3769 kcal kg^{-1}) and hulless (3800 kcal kg^{-1}) barley, respectively (Church, 1991). Likewise, the wheat and triticale GE values of the current study are slightly higher than previous reports of 3790 and 3750 kcal kg^{-1}, respectively, (Church, 1991).

GE values, although useful, are not as accurate as other measures of energy content, such as TME. Therefore, more accurate conclusions can be made from TME values.

True Metabolizable Energy

Rotter et al. (1990) reported energy values for barley in diets of broiler chicks using AMEn and in diets of adult roosters using TME_n. TME_n values for diets of 100% barley formulated from three hulled barley cultivars (3097, 2925, and 2997 kcal kg^{-1}), and one hulless barley cultivar (2658 kcal kg^{-1}) were reported. These TME_n values were slightly higher than those determined in the current study for Callao (2899 kcal kg^{-1}) and

Starling (2882 kcal kg^{-1}). TME_n values for hulless barley ranged from 2916 to 2995 kcal kg^{-1} in the present study and were considerably higher than those reported by Rotter et al. (1990) at 2677 kcal kg^{-1}. The TME_n value of hulless barley (2949 kcal kg^{-1}) reported by Church (1991) is very similar to TME_n values found in the present study. However, TME_n values reported by Church (1991) and Rossnagel et al. (1981) for hulled barley are on either extreme of the values determined in the present study. Jurgens (1988) reports slightly higher TME_n values for wheat and triticale (3093 and 3052 kcal kg^{-1}) compared to the values found for wheat and triticale in the current study (2868 and 2823 kcal kg^{-1}).

TME_n values for Callao (2899 kcal) and the hulless lines (ranging from 2916 to 2995 kcal kg^{-1}) from the current study are well above the NRC estimate of barley (2751 kcal kg^{-1}), and in fact, fall within the NRC poultry ME guidelines of 2899 to 3301 kcal kg^{-1}. Therefore, the hulled and hulless barley evaluated in the current study need no additional supplements added to the diet to increase the ME. This would allow such rations to be formulated at a lower cost compared to rations that are formulated from low-ME barley.

CONCLUSIONS

Results of the current study suggest that hulless barley has potential as an improved feed crop in the mid-Atlantic region. However, this will require development of improved hulless winter barley lines through breeding. The highest yielding hulless lines in this study (SC890573) produced grain yields that were 87% of those of hulled cultivar Callao, which was similar to those of previous reports (Rossnagel et al., 1981). The South Carolina lines were derived with very little breeding effort focused directly at development of improved hulless varieties. Test weights of hulless lines in the current study were very similar to those of wheat. Fiber concentrations of hulless lines were lower than those of hulled cultivars, and protein concentrations of hulless lines were higher than those of hulled lines. Significant differences were not observed between hulled and hulless barley for β-glucan or fat concentrations. Jackson and Trical 498 had very low levels of β-glucan when compared to hulled and hulless barley, but had similar concentrations of fat. TME_n did not differ significantly among entries, but tended to be lower for hulled barley than for hulless barley, wheat, and triticale. Overall, hulless barley line SC890585 performed the best compared to the other hulless lines.

Approximately 10% of the lines from the world collection were selected based on excellent threshability and seed color. With sufficient time and resources, yield of hulless winter barley genotypes can be increased over that of existing unadapted lines through traditional breeding methods. Test weight also has the potential to be increased through selection of plump-seeded varieties. Fiber concentration of the hulless lines examined was excellent, with average values lower than that of Jackson wheat. Beta-glucan concentration, although very similar to that of hulled barley and considerably higher than that of Jackson, is not an insurmountable problem due to the ability of β-glucanase to completely break down the β-glucan. TME_n values can be increased, with sufficient time and resources, to approach those of wheat. In fact hulless barley effectively combines the desirable traits of barley (higher fat concentration) and wheat (higher concentrations of protein, lower concentrations of fiber, and higher TME_n values).

Hulless barley can compete with hulled barley very effectively by offering lower fiber concentration and higher protein concentration. Hulless barley is also competitive with wheat by allowing double-crop soybeans to be planted ten days earlier, while having similar test weight and similar handling and storage. In the mid-Atlantic region, when compared to corn, hulless barley offers production dependability, and when coupled with double-crop soybeans provides an economically competitive crop scheme.

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TABLES

Table 1. Yield of hulled barley cultivars Callao and Starling, and six hulless barley lines in 1997.

	Locations[1]								
Entry	1	2	3	4	5	6	7	8	Average[2]
	kg ha^{-1}								
Callao	9532[a][3]	12276[a]	10107[ab]	10232[a]	7324[a]	6003[a][4]	6537[a]	9984[a]	8999
Starling	9761[a]	11408[a]	11482[a]	9710[a]	5731[ab]	6617[a]	7275[a]	10371[a]	9044
SC860934	5499[b]	8510[b]	8265[bc]	5911[bc]	4379[b]	4343[a]	4134[b]	6445[b]	5936
SC860972	5815[b]	7528[b]	8336[bc]	5411[bc]	4044[b]	3506[a]	3746[b]	5786[b]	5522
SC860974	5435[b]	7216[b]	7282[bc]	5360[bc]	3620[b]	5351[a]	3862[b]	5418[b]	5443
SC880248	4865[b]	7491[b]	8760[bc]	5810[bc]	4411[ab]	2954[a]	4377[b]	5951[b]	5577
SC890573	5272[b]	8005[b]	9088[abc]	6366[b]	4366[b]	4557[a]	4277[b]	6186[b]	6015
SC890585	5199[b]	8280[b]	8862[bc]	5862[bc]	4421[ab]	2551[a]	4238[b]	6125[b]	5636
Average[5]	6422	8839	9023	6833	4787	4485	4806	7033	6522

[1] 1-Blacksburg, VA; 2-Orange,VA; 3-Painter, VA; 4-Warsaw, VA; 5-Kinston, NC; 6-Rowan, NC; 7-Lexington, KY; 8-Keedysville, MD.
[2] Average yield over locations in 1997.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] High variation between replications caused an elevated coefficient of variation (c.v.=32%).
[5] Location average yield.

Table 2. Yield of Trical 498 triticale and Jackson wheat in Virginia in 1997.

	Location[1]				
Entry	1	2	3	4	Average[2]
	kg ha^{-1}				
Trical 498	11294[a][3]	8709[a]	12590[a]	8925[a]	10380
Jackson	8907[b]	8325[a]	11183[a]	5706[b]	8530
Average[4]	10101	8517	11887	7316	9455

[1] 1-Blacksburg, 2-Orange, 3-Painter, 4-Warsaw.
[2] Average yield over locations in 1997.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] Location average yield.

Table 3. Yield of hulled barley cultivars Callao and Starling, and six hulless barley lines in 1998.

	Locations[1]								
Entry	1	2	3	4	5	6	7	8	Average[2]
	kg ha^{-1}								
Callao	7717[ab][3]	7316[ab]	6299[bc]	10084[a]	3714[ab]	3534[a]	1182[e]	6394[ab]	5780
Starling	7934[a]	7421[a]	8460[a]	10418[a]	4229[a]	4843[a]	2352[b]	6737[a]	6549
SC860934	6450[dc]	5836[c]	6872[abc]	8293[bc]	2205[bc]	4199[a]	2593[cd]	5575[abc]	5253
SC860972	5365[de]	5715[c]	6080[bc]	7322[bc]	2780[abc]	4014[a]	2063[d]	4661[bc]	4750
SC860974	5281[e]	5299[c]	5508[c]	7179[c]	1493[c]	4635[a]	2426[cd]	3862[c]	4460
SC880248	6519[c]	6308[abc]	6626[bc]	8464[b]	2392[abc]	4276[a]	3137[bc]	4834[bc]	5021
SC890573	6614[bc]	5454[c]	6762[abc]	8026[bc]	2196[bc]	4190[a]	3653[a]	4754[bc]	5206
SC890585	7004[abc]	5912[bc]	7427[ab]	8464[b]	2536[abc]	4138[a]	3984[a]	5542[abc]	5626
Average[4]	6611	6158	6754	8531	2693	4229	2674	5295	5987

[1] 1-Blacksburg, VA; 2-Orange,VA; 3-Painter, VA; 4-Warsaw, VA; 5-Kinston, NC; 6-Rowan, NC; 7-Lexington, KY; 8-Keedysville, MD.
[2] Average yeild over locations in 1998.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] Location average yield.

Table 4. Yield of Trical 498 triticale and Jackson wheat in Virginia in 1998.

	Location[1]				
Entry	1	2	3	4	Average[2]
	kg ha^{-1}				
Trical 498	5195[a][3]	5400[b]	6912[a]	6199[a]	5927
Jackson	6663[a]	9029[a]	6921[a]	6358[a]	7243
Average[4]	5929	7215	6917	6279	6585

[1] 1-Blacksburg, 2-Orange, 3-Painter, 4-Warsaw.
[2] Average yield over locations in 1998.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] Location average yield.

Table 5. Yield of hulled barley cultivars Callao and Starling, and six hulless barley lines in 1999.

	Locations[1]								
Entry	1	2	3	4	5	6	7	8	Average[2]
	kg ha^{-1}								
Callao	9221[a][3]	8190[a]	6250[a]	8373[a]	6021[a]	6994[a]	5119[bc]	8055[a]	7278
Starling	8952[a]	7995[a]	7900[a]	7430[a]	5847[a]	5703[a]	5566[a]	7444[ab]	7105
SC860934	8653[a]	8458[a]	9788[a]	9118[a]	7614[a]	6558[a]	4231[c]	5561[b]	7498
SC860972	9086[a]	8451[a]	7590[a]	7886[a]	6829[a]	5429[a]	4395[c]	6343[ab]	7001
SC860974	10112[a]	7359[a]	7034[a]	7914[a]	5884[a]	6418[a]	4669[bc]	6288[ab]	6960
SC880248	8335[a]	8112[a]	8556[a]	9374[a]	6689[a]	7881[a]	5245[ab]	7481[ab]	7709
SC890573	9686[a]	9866[a]	7879[a]	8899[a]	7639[a]	6194[a]	5517[ab]	7576[ab]	7907
SC890585	9105[a]	7411[a]	8224[a]	9586[a]	7522[a]	7378[a]	5020[bc]	7371[ab]	7702
Average[4]	9144	8230	7903	8573	6756	6569	4970	7015	7395

[1] 1-Blacksburg, VA; 2-Orange,VA; 3-Painter, VA; 4-Warsaw, VA; 5-Kinston, NC; 6-Rowan, NC; 7-Lexington, KY; 8-Keedysville, MD.

[2] Average yield over locations in 1999.

[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).

[4] Location average yield.

Table 6. Yield of Trical 498 triticale and Jackson wheat in Virginia in 1999.

	Location[1]				
Entry	1	2	3	4	Average[2]
	kg ha^{-1}				
Trical 498	11549[a][3]	7987[b]	9235[b]	7403[b]	9044
Jackson	9393[b]	8683[a]	11604[a]	8420[a]	9525
Average[4]	10471	8335	10420	7912	9285

[1] 1-Blacksburg, 2-Orange, 3-Painter, 4-Warsaw.

[2] Average yield over locations in 1999.

[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).

[4] Location average yield.

Table 7. Test weight of hulled barley cultivars Callao and Starling, and six hulless barley lines in 1997.

	Locations[1]								
Entry	1	2	3	4	5	6	7	8	Average[2]
	kg m^{-3}								
Callao	603[cb3]	586[b]	630[b]	727[b]	653[cb]	672[ab]	637[b]	620[b]	641
Starling	550[c]	597[b]	601[b]	670[c]	615[c]	614[b]	597[c]	606[b]	606
SC860934	645[ab]	715[a]	774[a]	795[a]	730[a]	771[a]	713[a]	723[a]	733
SC860972	647[ab]	739[a]	765[a]	803[a]	717[ab]	719[ab]	707[a]	728[a]	728
SC860974	696[a]	736[a]	771[a]	805[a]	787[a]	705[ab]	712[a]	762[a]	747
SC880248	694[a]	737[a]	751[a]	813[a]	762[a]	748[a]	722[a]	750[a]	747
SC890573	690[a]	727[a]	764[a]	811[a]	749[a]	724[ab]	707[a]	738[a]	739
SC890585	688[a]	759[a]	777[a]	810[a]	760[a]	741[a]	711[a]	760[a]	751
Average[4]	652	700	729	779	722	712	688	711	712

[1] 1-Blacksburg, VA; 2-Orange,VA; 3-Painter, VA; 4-Warsaw, VA; 5-Kinston, NC; 6-Rowan, NC; 7-Lexington, KY; 8-Keedysville, MD.
[2] Average test weight over locations in 1997.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] Location average test weight.

Table 8. Test weight of Trical 498 triticale and Jackson wheat in Virginia in 1997.

	Location[1]				
Entry	1	2	3	4	Average[2]
	kg m^{-3}				
Trical 498	656[b3]	712[b]	697[b]	697[b]	691
Jackson	762[a]	798[a]	801[a]	798[a]	790
Average[4]	709	755	749	748	741

[1] 1-Blacksburg, 2-Orange, 3-Painter, 4-Warsaw.
[2] Average test weight over locations in 1997.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] Location average test weight.

Table 9. Test weight of hulled barley cultivars Callao and Starling, and six hulless barley lines in 1998.

Entry	Locations[1]								
	1	2[2]	3	4	5	6	7	8	Average[3]
	kg m^{-3}								
Callao	564^{c4}		581^{e}	614^{b}	590^{ab}	607^{d}	523^{c}	588^{g}	581
Starling	518^{d}		558^{f}	580^{b}	558^{b}	558^{e}	480^{d}	532^{h}	541
SC860934	648^{b}		704^{a}	711^{a}	650^{ab}	751^{abc}	658^{a}	655^{f}	682
SC860972	670^{ab}		683^{bc}	721^{a}	702^{a}	737^{ab}	646^{a}	725^{b}	698
SC860974	696^{a}		691^{ab}	729^{a}	708^{a}	750^{a}	631^{ab}	727^{a}	705
SC880248	689^{a}		695^{ab}	745^{a}	709^{a}	735^{abc}	659^{a}	685^{c}	702
SC890573	643^{b}		658^{d}	721^{a}	653^{ab}	705^{c}	608^{b}	680^{d}	667
SC890585	647^{b}		671^{cd}	730^{a}	701^{a}	710^{bc}	628^{ab}	667^{e}	679
Average[5]	634		655	694	659	694	604	657	657

[1] 1-Blacksburg, VA; 2-Orange,VA; 3-Painter, VA; 4-Warsaw, VA; 5-Kinston, NC; 6-Rowan, NC; 7-Lexington, KY; 8-Keedysville, MD.
[2] Test weight data not available at Orange, VA in 1998.
[3] Average test weight over locations in 1998.
[4] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[5] Location average test weights.

Table 10. Test weight of Trical 498 triticale and Jackson wheat in Virginia in 1998.

Entry	Location[1]				
	1	2	3	4	Average[2]
	kg m^{-3}				
Trical 498	551^{b3}	586^{b}	566^{b}	562^{b}	566
Jackson	702^{a}	716^{a}	705^{a}	710^{a}	708
Average[4]	627	651	636	636	637

[1] 1-Blacksburg, 2-Orange, 3-Painter, 4-Warsaw.
[2] Average test weight over locations in 1998.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] Location average test weight.

Table 11. Test weight of hulled barley cultivars Callao and Starling, and six hulless barley lines in 1999.

	Locations[1]								
Entry	1	2	3	4	5	6	7	8	Average[2]
	kg m^{-3}								
Callao	717[a3]	757[a]	766[a]	805[a]	847[a]	764[a]	583[a]	639[a]	735
Starling	740[a]	772[a]	760[ab]	813[a]	812[a]	815[a]	544[a]	457[a]	714
SC860934	729[a]	759[a]	672[b]	746[a]	756[a]	737[a]	544[a]	575[a]	690
SC860972	731[a]	722[a]	726[ab]	774[a]	754[a]	794[a]	550[a]	773[a]	728
SC860974	752[a]	784[a]	767[a]	814[a]	797[a]	830[a]	533[a]	780[a]	757
SC880248	739[a]	776[a]	728[ab]	800[a]	828[a]	771[a]	553[a]	773[a]	746
SC890573	745[a]	722[a]	742[ab]	794[a]	765[a]	824[a]	575[a]	760[a]	741
SC890585	714[a]	778[a]	749[ab]	771[a]	773[a]	770[a]	579[a]	764[a]	737
Average[4]	733	759	739	790	792	788	558	690	731

[1] 1-Blacksburg, VA; 2-Orange,VA; 3-Painter, VA; 4-Warsaw, VA; 5-Kinston, NC; 6-Rowan, NC; 7-Lexington, KY; 8-Keedysville, MD.
[2] Average test weight over locations in 1999.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] Location average test weight.

Table 12. Test weight of Trical 498 triticale and Jackson wheat in Virginia in 1999.

	Location[1]				
Entry	1	2	3	4	Average[2]
	kg m^{-3}				
Trical 498	684[b3]	710[b]	583[b]	650[b]	657
Jackson	799[a]	774[a]	735[a]	763[a]	768
Average[4]	742	742	659	707	713

[1] 1-Blacksburg, 2-Orange, 3-Painter, 4-Warsaw.
[2] Average test weight over locations in 1999.
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[4] Location average test weight.

Table 13. Average heading date, height, and lodging scores of hulled barley cultivars Callao and Starling, and six hulless barley lines grown at Blacksburg and Warsaw, Virginia in 1997, 1998, and 1999.

	Location					
	Blacksburg			Warsaw		
Line	Heading Date	Height	Lodging	Heading Date	Height	Lodging
	Days[1]	cm	0.2-10[2]	Days	cm	0.2-10
Callao	114	90	3.7	102	89	5.4
Starling	118	100	3.3	107	102	1.8
SC860934	117	102	0.9	103	101	2.8
SC860972	119	97	3.8	105	99	4.4
SC860974	120	99	4.3	105	102	5.4
SC880248	118	97	0.3	104	95	0.9
SC890573	117	95	2.0	103	96	1.1
SC890585	116	95	2.4	102	94	0.5

[1] Julia scale: Number of days from 1 January.
[2] Belgian scale: Product of area (1-10) and intensity (1-5) multiplied by 0.2.

Table 14. Average heading date[1], height, and lodging data from state wheat test at two locations in Virginia[2] for 1997, 1998, and 1999.

	Heading Date		Plant Height		Lodging[3]	
Line	1	2	1	2	1	2
	— Days —		— cm —		0.2-10	
Trical 498	124	103	114	106	3.8	1.6
Jackson	132	118	96	93	7.4	1.6

[1]Julian scale — days from 1 January.
[2]1-Blacksburg, 2-Warsaw.
[3]Belgian scale: Product of area (1-10) and intensity (1-5) multiplied by 0.2.

Table 15. Heading date, height, and lodging scores of hulled barley cultivars Callao and Starling, and six hulless barley lines grown at Blacksburg and Warsaw, Virginia in 1997.

Line	Blacksburg Heading Date	Blacksburg Height	Blacksburg Lodging	Warsaw Heading Date	Warsaw Height	Warsaw Lodging
	Days[1]	cm	0.2-10[2]	Days	cm	0.2-10
Callao	118[a3]	91[ab]	0.3[a]	102[ab]	93[a]	6.0[c]
Starling	124[cd]	104[c]	0.4[a]	110[e]	110[d]	1.7[ab]
SC860934	122[b]	100[bc]	0.2[a]	101[a]	105[cd]	3.9[bc]
SC860972	125[d]	95[abc]	0.4[a]	105[cd]	100[bc]	4.5[c]
SC860974	125[d]	97[abc]	0.3[a]	105[d]	104[c]	5.4[c]
SC880248	123[bc]	94[abc]	0.2[a]	103[bc]	93[a]	1.5[ab]
SC890573	122[b]	87[a]	0.2[a]	102[ab]	91[a]	1.8[ab]
SC890585	122[b]	91[ab]	0.3[a]	102[ab]	95[ab]	0.6[a]

[1]Julian scale: Number of days from 1 January.
[2]Belgian scale: Product of area (1-10) and intensity (1-5) multiplied by 0.2.
[3]Means followed by the same letter are not significantly different based on Tukey test (P>0.05).

Table 16. Heading date[1], height, and lodging data from state wheat test at two locations in Virginia[2] for 1997.

Line	Heading Date 1	Heading Date 2	Plant Height 1	Plant Height 2	Lodging[3] 1	Lodging[3] 2
	Days		cm		0.2-10	
Trical 498	123[a4]	103[a]	126[a]	121[a]	-[5]	-
Jackson	136[b]	122[b]	98[b]	93[b]	-	-

[1]Julian scale — days from 1 January.
[2]1-Blacksburg, 2-Warsaw.
[3]Belgian scale: Product of area (1-10) and intensity (1-5) multiplied by 0.2.
[4]Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[5]No lodging occurred.

Table 17. Heading date, height, and lodging scores of hulled barley cultivars Callao and Starling, and six hulless barley lines grown at Blacksburg and Warsaw, Virginia in 1998.

	Location					
	Blacksburg			Warsaw		
Line	Heading Date	Height	Lodging	Heading Date	Height	Lodging
	Days[1]	cm	0.2-10[2]	Days	cm	0.2-10
Callao	108[a][3]	84[a]	8.8[d]	101[a]	77[a]	4.8[b]
Starling	116[cd]	103[bc]	2.9[abc]	106[bc]	97[bcd]	1.9[ab]
SC860934	112[b]	110[c]	2.0[ab]	102[a]	104[d]	1.7[ab]
SC860972	116[cd]	96[b]	7.0[cd]	106[bc]	101[cd]	4.3[ab]
SC860974	117[d]	103[bc]	5.0[bcd]	108[c]	102[cd]	5.4[b]
SC880248	116[cd]	105[bc]	0.3[a]	104[b]	96[bc]	0.3[a]
SC890573	115[c]	104[bc]	0.3[a]	105[b]	100[cd]	0.3[a]
SC890585	113[b]	104[bc]	1.9[ab]	101[a]	93[b]	0.3[a]

[1] Julian scale: Number of days from 1 January
[2] Belgian lodging scale: Product of area (1-10) and intensity (1-5) multiplied by 0.2
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05)

Table 18. Heading date[1], height, and lodging data from state wheat test at two locations in Virginia[2] for 1998.

	Heading Date		Plant Height		Lodging[3]	
Line	1	2	1	2	1	2
	— Days —		— cm —		0.2-10	
Trical 498	126[a][4]	106[a]	112[a]	99[a]	3.8[b]	3.0[a]
Jackson	128[a]	112[b]	99[b]	88[b]	7.4[a]	0.8[b]

[1]Julian scale — days from 1 January.
[2]1-Blacksburg, 2-Warsaw
[3]Belgian scale: Product of area (1-10) and intensity (1-5) multiplied by 0.2
[4]Means followed by the same letter are not significantly different based on Tukey test (P>0.05)

Table 19. Heading date, height, and lodging scores of hulled barley cultivars Callao and Starling, and six hulless barley lines grown at Blacksburg and Warsaw, Virginia in 1999.

Line	Blacksburg			Warsaw	
	Heading date	Height	Lodging	Heading date	Height
	Days[1]	— cm —	0.2-10[2]	Days	— cm —
Callao	116[ab3]	92[a]	6.6[ab]	104[a]	98[a]
Starling	115[ab]	96[a]	2.2[ab]	105[a]	100[a]
SC860934	116[ab]	95[a]	0.6[a]	105[a]	95[a]
SC860972	116[ab]	100[a]	4.0[ab]	105[a]	97[a]
SC860974	117[b]	97[a]	7.5[b]	103[a]	100[a]
SC880248	116[ab]	92[a]	0.4[a]	104[a]	95[a]
SC890573	115[ab]	95[a]	5.5[ab]	103[a]	97[a]
SC890585	114[a]	90[a]	4.9[ab]	103[a]	94[a]

[1]Julian scale: Number of days from 1 January.
[2]Belgian scale: Product of area (1-10) and intensity (1-5) multiplied by 0.2.
[3]Means followed by the same letter are not significantly different based on Tukey test (P>0.05).

Table 20. Heading date[1], height, and lodging data from state wheat test at two locations in Virginia[2] for 1999.

Line	Heading Date		Plant Height		Lodging[3]	
	1	2	1	2	1	2
	— Days —		— cm —		0.2-10	
Trical 498	123[a4]	100[a]	105[a]	97[a]	0.2	-[5]
Jackson	131[b]	119[b]	92[b]	99[a]	2.3	-

[1]Julian scale — days from 1 January.
[2]1-Blacksburg, 2-Warsaw.
[3]Belgian scale: Product of area (1-10) and intensity (1-5) multiplied by 0.2.
[4]Means followed by the same letter are not significantly different based on Tukey test (P>0.05).
[5]No lodging occurred.

Table 21. Fiber and Beta-glucan analysis of hulled barley cultivars Callao and Starling, six hulless barley lines, Trical 498 triticale, and Jackson wheat samples combined over locations[1] for each year, and over years[2].

	Year							
	1997		1998		1999		1997-99	
Entry	Fiber	β-glucan	Fiber	β-glucan	Fiber	β-glucan	Fiber	β-glucan
	%							
Callao	4.70[b3]	5.67[ab]	4.41[b]	3.99[a]	4.46[b]	4.20abc	4.52[b*]	4.70[ab]
Starling	5.05[a]	4.89[bc]	5.11[a]	3.61[bc]	5.00[a]	4.08abc	5.05[a]	4.25[bc]
SC860934	2.21[de]	6.13[a]	1.87[d]	4.15[a]	1.82[ef]	4.53a	1.97[fg]	4.94[a]
SC860972	2.64[c]	4.76[c]	1.99[d]	3.05[d]	1.89[e]	3.51c	2.17[e]	3.77[c]
SC860974	2.32[d]	4.73[c]	2.05[d]	3.17[cd]	1.94[e]	3.66bc	2.10[ef]	3.85[c]
SC880248	1.96[e]	5.74[a]	1.80[d]	4.39[a]	1.64[f]	4.51a	1.80[g]	4.88[a]
SC890573	2.13[de]	4.94[bc]	1.79[d]	3.20[cd]	1.72[ef]	3.76bc	1.88[g]	3.97[c]
SC890585	2.32[d]	5.84[a]	1.96[d]	3.40[cd]	1.94[e]	4.27ab	2.07[e]	4.50[ab]
Trical 498	2.77[c]	0.62[d]	2.87[c]	0.12[e]	2.94[c]	1.05d	2.86[c]	0.64[d]
Jackson	2.69[c]	0.58[d]	2.63[c]	0.09[e]	2.50[d]	1.17d	2.60[d]	0.65[d]

[1] Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston, and Rowan, NC; Lexington, KY; Keedysville, MD.
[2] 1997, 1998, and 1999
[3] Means followed by the same letter are not significantly different based on Tukey test (P>0.05)

Table 22. Nutrient analyses of hulled barley cultivars Callao and Starling and six hulless barley lines, Trical 498 triticale, and Jackson wheat combined over locations[1] for 1997.

Entry	Gross Energy	Protein	Fat	Fiber	Ash	TME_n
	— kcal kg^{-1} —			%		— kcal kg^{-1} —
Callao	3917	9.90	1.58	4.43	1.75	3119[ab2]
Starling	3903	9.32	1.40	6.05	1.95	3009[bcd]
SC860934	3922	10.88	1.45	2.28	1.87	3052[abcd]
SC860972	3912	10.84	1.50	2.28	1.74	3124[ab]
SC860974	3881	10.88	1.45	2.28	1.74	3042[bcd]
SC880248	3951	11.67	1.10	1.96	1.89	3186[a]
SC890573	3896	10.78	1.87	2.26	2.77	2968[cd]
SC890585	3896	10.67	1.69	2.33	1.70	2976[cd]
Trical 498	3853	10.99	1.66	2.56	1.72	3066[abc]
Jackson	3872	11.84	1.31	2.56	1.61	2918[d]

[1]Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston, and Rowan, NC; Lexington, KY; Keedysville, MD.

[2]Means followed by the same letter are not significantly different based on Tukey test (P>0.05)

Table 23. Nutrient analyses of hulled barley cultivars Callao and Starling and six hulless barley lines, Trical 498 triticale, and Jackson wheat combined over locations[1] for 1998.

Entry	Gross Energy	Protein	Fat	Fiber	Ash	TME_n
	— kcal kg^{-1} —			%		—kcal kg^{-1}—
Callao	3903	11.64	1.58	3.54	1.99	2894[de2]
Starling	3865	11.75	1.39	4.79	2.27	2823[e]
SC860934	3862	11.85	1.55	1.61	1.82	2916[cde]
SC860972	3881	13.19	1.46	1.28	1.79	2983[abcd]
SC860974	3898	13.18	1.48	1.68	1.86	2944[bcde]
SC880248	3853	11.63	1.39	1.04	1.73	3016[abc]
SC890573	3855	11.91	1.40	1.14	1.77	3009[abcd]
SC890585	3867	11.94	1.43	1.28	1.81	3064[ab]
Trical 498	3826	11.46	1.53	2.42	2.00	2959[abcde]
Jackson	3843	11.53	1.28	1.98	1.69	3093[a]

[1]Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston, and Rowan, NC; Lexington, KY; Keedysville, MD.
[2]Means followed by the same letter are not significantly different based on Tukey test (P>0.05)

Table 24. Nutrient analyses of hulled barley cultivars Callao and Starling and six hulless barley lines, Trical 498 triticale, and Jackson wheat combined over locations[1] for 1999.

Entry	Gross Energy	Protein	Fat	Fiber	Ash	TME_n
	— $kcal\ kg^{-1}$ —			%		— $kcal\ kg^{-1}$ —
Callao	3891	9.80	1.60	4.62	2.04	2686[b2]
Starling	3905	10.28	1.21	4.87	1.96	2818[ab]
SC860934	3867	10.38	1.72	1.86	1.43	2780[ab]
SC860972	3889	11.17	1.54	1.91	1.63	2808[ab]
SC860974	3910	11.75	1.06	2.13	1.60	2808[ab]
SC880248	3905	10.61	1.07	1.92	1.59	2782[ab]
SC890573	3879	10.38	1.48	1.96	1.60	2858[ab]
SC890585	3869	10.23	1.56	2.03	1.57	2928[a]
Trical 498	3860	11.08	1.21	2.94	1.80	2823[ab]
Jackson	3915	14.33	1.21	2.69	1.30	2868[ab]

[1]Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston, and Rowan, NC; Lexington, KY; Keedysville, MD.

[2]Means followed by the same letter are not significantly different based on Tukey test (P>0.05)

Table 25. Nutrient analyses of hulled barley cultivars Callao and Starling and six hulless barley lines, Trical 498, and Jackson wheat averaged over locations[1] and years[2].

Entry	Gross Energy	Protein	Fat	Fiber	Ash	TME_n
	kcal kg^{-1}	– % –	–%–	–%–	–%–	kcal kg^{-1}
Callao	3903[a3]	10.45[b]	1.59[a]	4.20[b]	1.93[ab]	2899[a]
Starling	3891[ab]	10.45[b]	1.33[abcd]	5.24[a]	2.06[a]	2882[a]
SC860934	3884[ab]	11.04[ab]	1.57[ab]	1.92[cd]	1.71[ab]	2916[a]
SC860972	3893[a]	11.73[ab]	1.50[abc]	1.82[cd]	1.72[ab]	2971[a]
SC860974	3896[a]	11.94[ab]	1.33[bcd]	2.03[cd]	1.73[ab]	2933[a]
SC880248	3903 [a]	11.30[ab]	1.19[d]	1.64[d]	1.74[ab]	2995[a]
SC890573	3877[ab]	11.02[ab]	1.59[ab]	1.79[d]	2.05[a]	2944[a]
SC890585	3877[ab]	10.95[ab]	1.56[ab]	1.88[cd]	1.69[ab]	2990[a]
Trical 498	3846[b]	11.18[ab]	1.47[abc]	2.64[c]	1.84[ab]	2949[a]
Jackson	3877[ab]	12.57[a]	1.27[cd]	2.41[cd]	1.53[b]	2959[a]

[1]Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston, and Rowan, NC; Lexington, KY; Keedysville, MD.

[2]1997, 1998, and 1999

[3]Means followed by the same letter are not significantly different based on Tukey test (P>0.05)

Table 26. Correlation (r values) analyses of gross energy, TME[1], fiber, β-glucan, protein, fat, and ash of hulled barley cultivars Callao and Starling, six hulless barley lines, Trical 498 triticale, and Jackson wheat over eight locations[2] in 1997, 1998, and 1999.

	Gross Energy	TME	Fiber	β-glucan	Protein	Fat	Ash
TME	0.11[3]						
	0.561[4]						
Fiber	0.25	-0.22					
	0.181	*0.244*					
β-glucan	0.62	0.12	0.12				
	0.001	*0.541*	*0.579*				
Protein	-0.05	0.07	-0.47	-0.44			
	0.779	*0.724*	*0.009*	*0.016*			
Fat	-0.25	0.07	-0.01	0.20	-0.28		
	0.187	*0.714*	*0.961*	*0.296*	*0.133*		
Ash	0.01	0.07	0.33	0.20	-0.19	0.34	
	0.945	*0.712*	*0.077*	*0.289*	*0.319*	*0.063*	

[1] True Metabolizable Energy.
[2] Blacksburg, Orange, Painter, and Warsaw, VA; Kinston and Rowan, NC; Lexington, KY; and Keedysville, MD.
[3] Correlation r values.
[4] Probability (P#0.05 based on Pearson coefficient).

Table 27. Eighty hulless barley lines selected as potential parents from the world collection based on reaction to races 8 and 30 of leaf rust and powdery mildew, and characterization for seed color, starch type, heading date, and awn type.

Accession[1]		Genotype name or designation[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
PI	264457	Zun Paku Mugi	Japan	1	2	107	1	MS	23C	12
PI	26459	Kama-ore	Japan	3	3	106	2	I	4	12
PI	34129	Taihu	China	1	2	104	2	I	4	;2
PI	39365	Eremo	India	3	2	100	1	R	4	234
PI	41156	Dehra	India	1	2	102	1	R	4	;1
CIho	1373	Purple Nepal	USA	7	1	109	0	MRI	4	;1N
CIho	1374	Takeshita	Japan	1	2	108	1	MSI	23C	234
CIho	2239	Eremo	India	4	2	100	1	R	4	;1
CIho	2457	Lokian	China	3	2	98	2	MSI	4	12
PI	87775	Shimabara	Korea	3	3	105	1	MR	4	4
PI	87778	Hadakamugi	Korea	1	3	105	2	S	4	4
CIho	6041	Kobai	Japan	3	3	101	1	I	4	4
CIho	6045	Shinkiki	USA	3	3	107	1	MSI	23C	234
CIho	6601		Afghanistan	4	3	109	2	MS	4	4
CIho	6706		India	3	3	109	2	MR	4	4
PI	155101	Wase Hadaka	Japan	1	3	100	1	MR	4	4
CIho	7334	EhimeHadaka No. 1	Japan	3	2	104	2	MRI	4	4
CIho	7335	EijoHadaka	Japan	3	3	102	1	MRI	3C	234
CIho	7338	JoshuShirohadaka	Japan	3	3	102	1	I	4	4
CIho	7339	KagawaHadaka 1	Japan	3	3	103	1	MRI	3CN	4
CIho	7340	KairyoShirohadaka	Japan	1	3	106	1	I	4	4
CIho	7341	Kamaon 1	Japan	1	3	102	2	MSI	4	4
CIho	7343	KobaiSai	Japan	1	3	102	1	I	4	4
CIho	7344	Kobinkatagi	Japan	1	3	108	1	MRI	4	4
CIho	7346	KochiWasehadaka	Japan	3	3	97	2	MR	4	4
CIho	7348	Nejire 2	Japan	3	3	105	1	S	4	4
CIho	7349	OitaHadaka	Japan	1	3	107	1	I	3C	234
CIho	7352	Shikke Shirazu	Japan	1	3	105	1	S	4	4
PI	157667	ChinAnDong	Korea	3	2	105	2	I	4	23
PI	157675	KabinKataki 4	Korea	4	3	106	1	MRI	4	23
PI	157683	OWi	Korea	1	3	104	1	MSI	4	4
PI	157686	SamTo	Korea	3	2	103	1	MRI	4	4
PI	176059	Tsema	India	4	3	104	2	MRR	4	4
PI	176118	Oowajao	India	3	3	102	2	MRR	4	4
PI	176135	Oowajao	India	3	3	99	2	MS	4	4
PI	181090	Oowajao	India	3	3	100	2	MSI	4	4
PI	182603	Kairyo Hadaka	Japan	3	3	102	1	MR	3C	4
PI	182605	Sangatsu Hadak No. 1	Japan	3	3	94	2	I	4	4
PI	182610	Aizu Hadaka	Japan	1	2	112	1	S	4	4
PI	182611	Osaka No. 6	Japan	3	3	111	1	S	3C	4
PI	182613	Kobai No. 10	Japan	3	3	101	1	I	4	4
PI	182614	Kagoshima Kobai	Japan	3	3	106	1	MS	4	4

Table 27 (cont.). Eighty hulless barley lines selected as potential parents from the world collection based on reaction to races 8 and 30 of leaf rust and powdery mildew, and characterization for seed color, starch type, heading date, and awn type.

Accession[1]		Genotype name or designation[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
PI	182616	Mikuriya	Japan	3	3	102	1	MRI	4	4
PI	182617	Mihohadaka	Japan	3	3	105	1	MSI	4	4
PI	182629	Ichinenmugi No. 2	Japan	3	3	105	2	S	4	4
PI	182630	Tokushima Kagawa No. 5	Japan	3	3	102	1	MR	4	4
PI	182631	Kagawa Hadaka	Japan	1	3	105	1	I	4	4
PI	182632	Michima Hadaka	Japan	3	3	105	1	I	4	4
PI	190268	HenroHen	Japan	3	3	101	1	I	4	4
PI	190269	Henro 108	Japan	3	3	104	1	MS	4	4
PI	190270	Kairyo Bozu	Japan	1	3	104	1		4	4
PI	190706	Shanghai 1	China	1	4	102	2	MS	4	4
PI	190713	Marumi No. 16	Japan	3	3	105	2	MS	4	4
PI	190750	Kokubi 1	Japan	1	2	104	2	I	4	4
PI	190752	Yakko No. 52	Japan	7	3	107	2	S	4	4
PI	190753	Akashinriki	Japan	3	3	104	1	MS	4	4
PI	190765	Yanehadaka No. 2	Japan	4	3	100	1	I	23C	4
PI	190770	KochiWasehadaka	Japan	3	3	93	2	MRI	4	234
PI	190841	Chosindo Hadaka	Korea	1	3	110	2	MS	4	4
PI	190846	Fuanwaisarupori	Korea	1	3	107	1	S	4	4
PI	225016	ChoshiroHen	Japan	3	2	112	1	MS	4	4
CIho	10547		China	4	1	93	2	S	4	4
PI	242106	Isehadaka	Japan	3	1	107	1	MR	4	4
CIho	10625	Hakuto	Japan	3	1	106	1	S	4	4
PI	294726	Jane Hadaka	Bulgaria	3	1	105	1	I	4	4
CIho	16278	Isogenic: 141n8	USA	4	2	119	2	S	4	4
PI	327991	Wase Hadaka	Japan	3	3	105	1	MSI	4	4
PI	328959	Hor 2503	China	4	2	95	2	I	4	4
PI	371335	1970BA	Switzerland	4	2	111	2	I	23	4
PI	371346	1972A	Switzerland	4	2	108	2	I	23	4
PI	429560	NB61A	Nepal	3	3	102	2	I	12	4
PI	565674	Lu Ren Da Mai	China	4	3	99	H	MRI	4	4
PI	565678	Huo Deng Mang	China	3	3	108	2	MSI	4	4
PI	565973	117002	China	3	3	107	2	MS	4	4
PI	566014	Lao Wu Hu Xu Mai	China	3	3	104	2	S	4	4
PI	566034	Zao Bai Qing Ke	China	3	3	102	2	MS	4	4
PI	566348	117870	China	1	2	105	2	I	4	4
PI	566350	117881	China	1	2	107	H	I	4	4
PI	566394	Mi Mai	China	3	2	105	2	MS	23	4

[1]Acession number assigned by USDA-ARS Aberdeen, ID
[2]Name of cultivar from country of origin
[3]Cultivar country of origin
[4]Color of seed on a scale of 1 to 10, 1=very light brown, 2=light brown, 3=light/dark brown, 4=brown blue, 5=blue, 6=blue/brown/purple, 7=brown/purple, 8=dark purple
[5]1 to 3=starchy, 4 and 5=waxy
[6]Julian heading date-days from 1 January
[7]Awn type, 0=awnless, 1=short awned, 2=long awned, H=hooded
[8]Powdery mildew reaction, R=resistant, MR=moderately resistant, I=intermediate, MS=moderately susceptible, S=susceptible,
[9]Infection type, 0-1=resistant, 2=moderately resistant, 3=moderately susceptible, 4=susceptible, + =increased susceptibility, - =decreased suscepibility, ; =necrotic flecking resistance reaction, C=chlorotic reaction, N=necrotic reaction

FIGURES

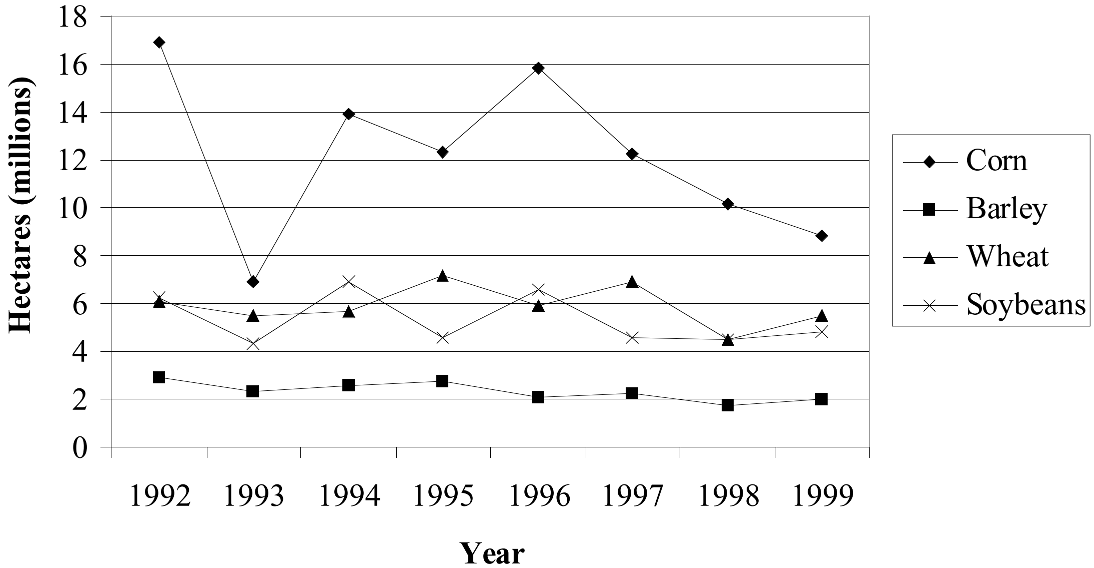

Fig. 1. Annual mean production of corn, barley, wheat, and soybeans harvested for grain in Virginia for 1992 through 1999. (Source: Virginia Department of Agriculture and Consumer Services)

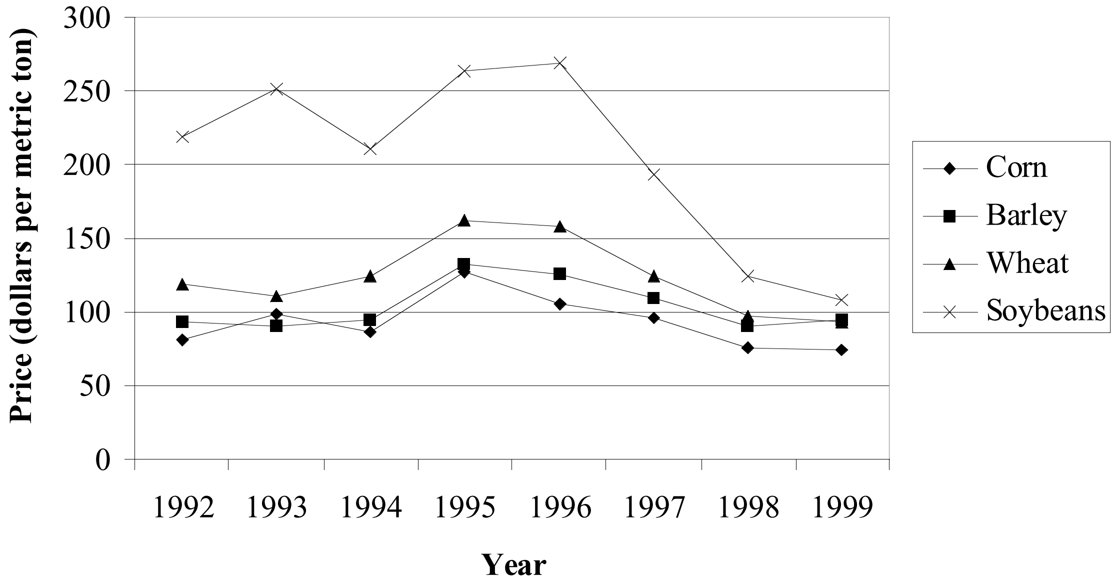

Fig. 2. Annual mean price of corn, barley, wheat, and soybean in Virginia for 1992 through 1999. (Source: Virginia Department of Agriculture and Consumer Services)

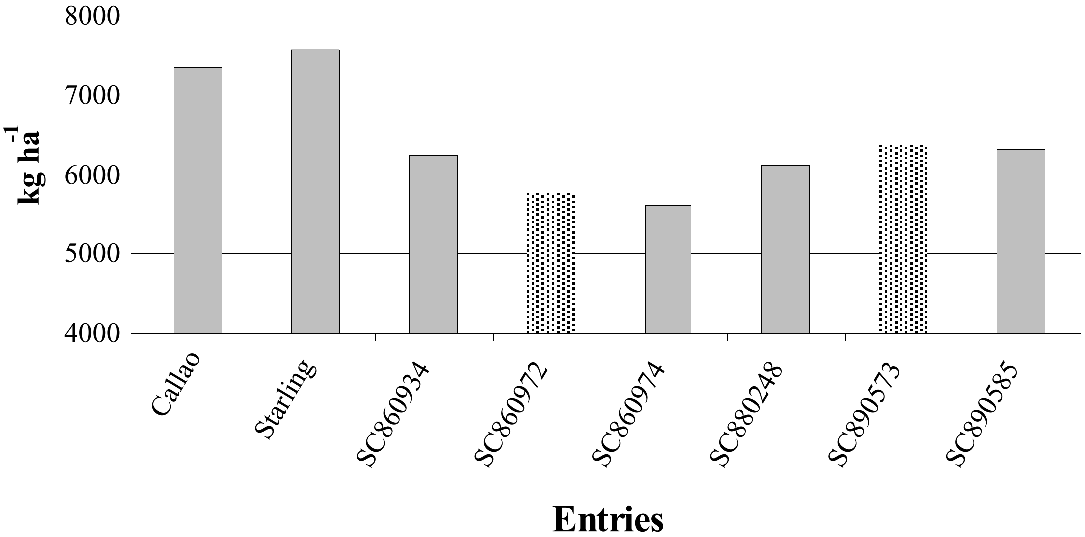

Fig. 3. Mean yield of hulled barley cultivars Callao and Starling, and six hulless barley lines averaged over eight locations (Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland) and over three years (1997, 1998, and 1999).

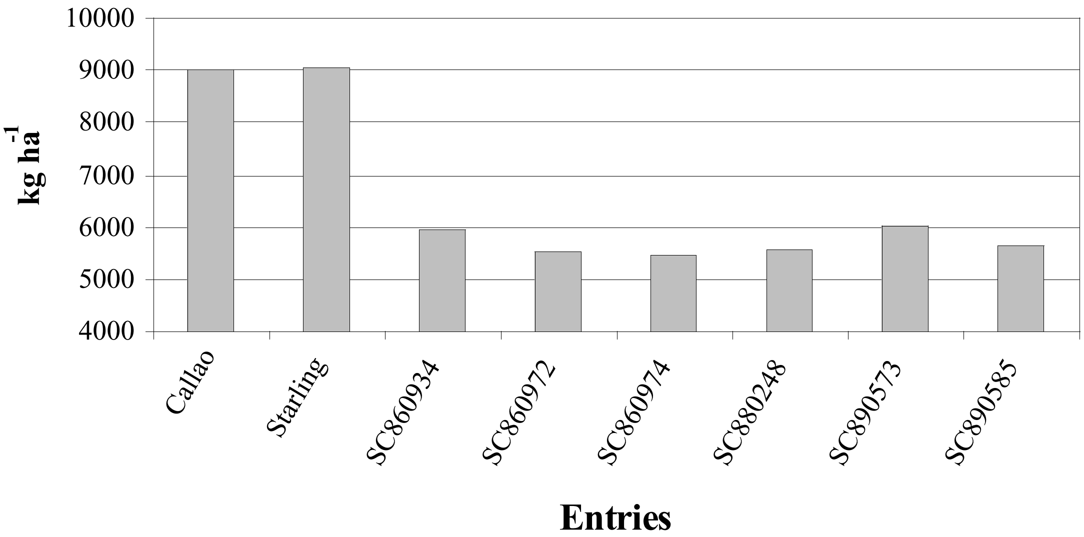

Fig. 4. Mean yield of hulled barley cultivars Callao and Starling, and six hulless barley lines averaged over eight locations (Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland) in 1997.

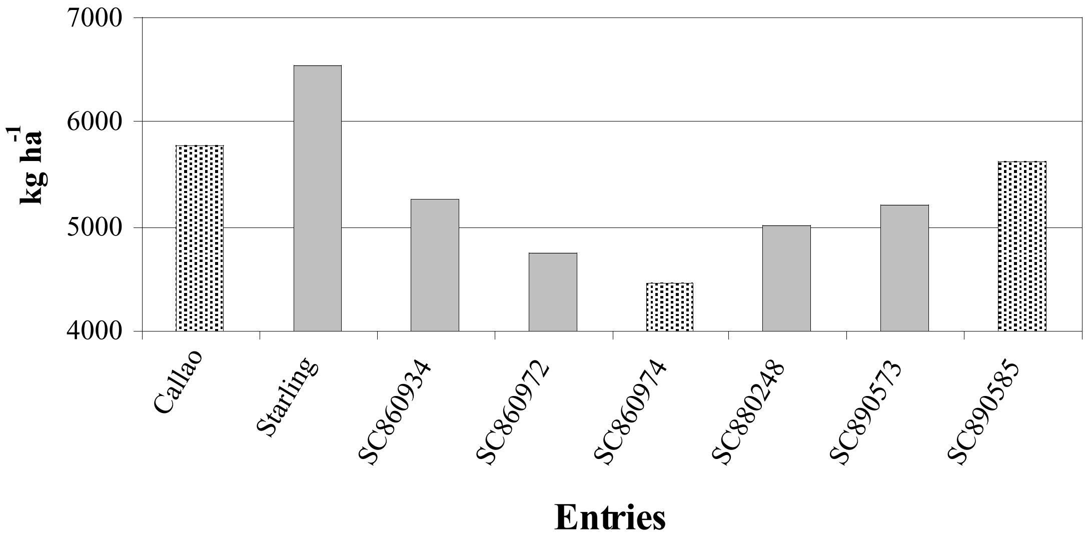

Fig. 5. Mean yield of hulled barley cultivars Callao and Starling, and six hulless barley lines averaged over eight locations (Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland) in 1998.

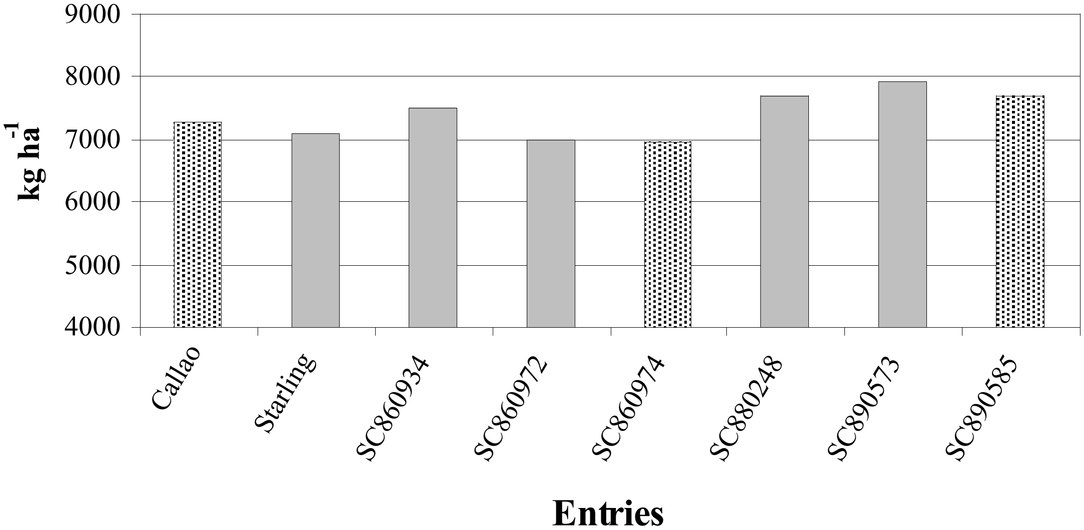

Fig. 6. Mean yield of hulled barley cultivars Callao and Starling, and six hulless barley lines averaged over eight locations (Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland) in 1999.

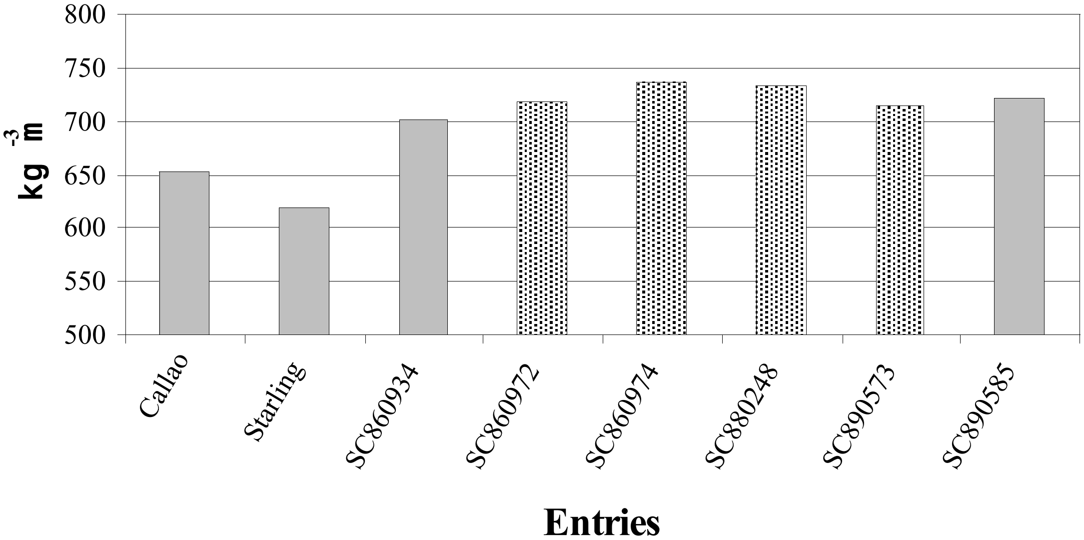

Fig. 7. Mean test weight of hulled barley cultivars Callao and Starling, and six hulless barley lines averaged over eight locations (Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland) and over three years (1997, 1998, and 1999).

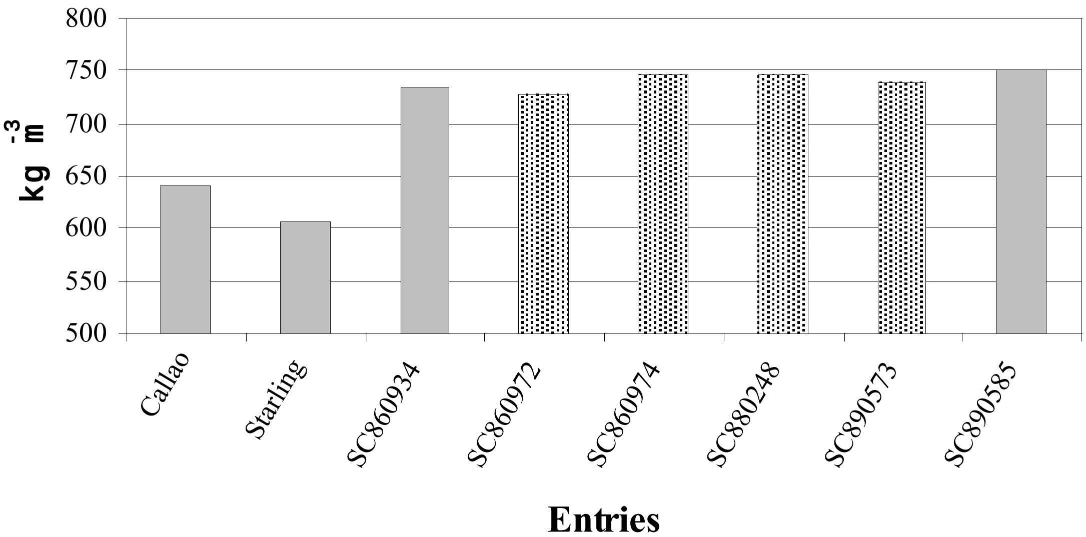

Fig. 8. Mean test weight of hulled barley cultivars Callao and Starling, and six hulless barley lines averaged over eight locations (Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland) in 1997.

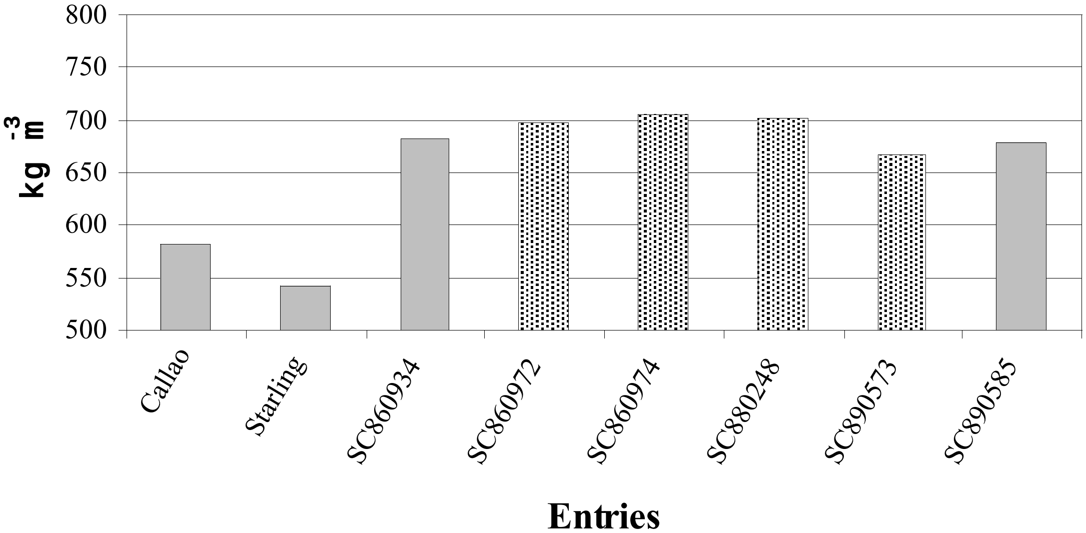

Fig. 9. Mean test weight of hulled barley cultivars Callao and Starling, and six hulless barley lines averaged over eight locations (Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland) in 1998.

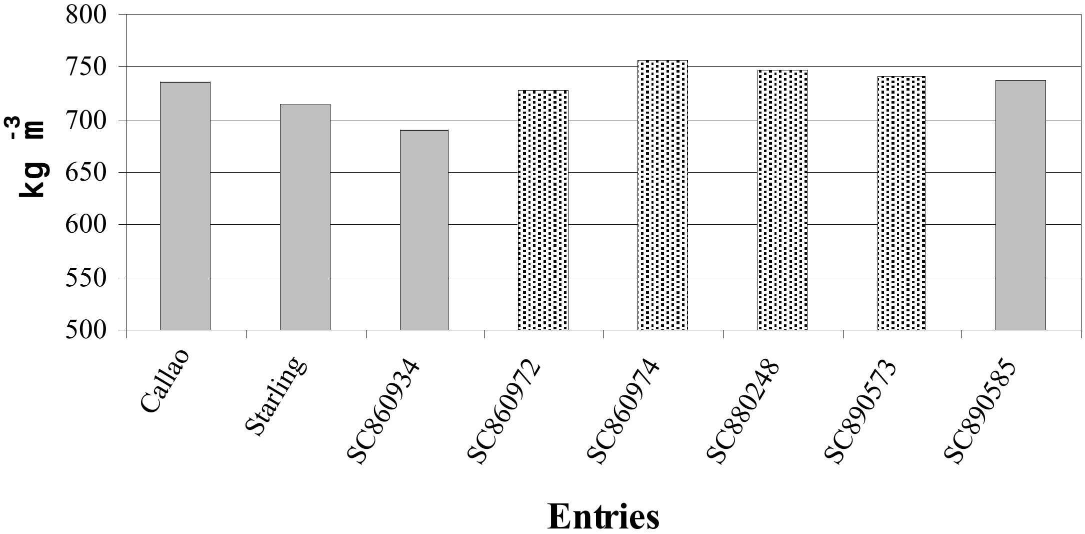

Fig. 10. Mean test weight of hulled barley cultivars Callao and Starling, and six hulless barley lines averaged over eight locations (Blacksburg, Orange, Painter, and Warsaw, Virginia; Kinston and Rowan, North Carolina; Lexington, Kentucky; and Keedysville, Maryland) in 1999.

CHAPTER III

EVALUATION OF HULLED AND HULLESS BARLEY IN DIETS OF 21 TO 42 DAY OLD BROILERS

ABSTRACT

Barley (*Hordeum vulgare* L.) has not been used extensively in diets of vertically integrated poultry and swine operations due to high fiber concentration, low metabolizable energy (ME), and anti-nutritive factors such as β-glucan. Addition of the enzyme β-glucanase in the diet negates the effects of β-glucan and, therefore, it is not essential that barley varieties with low levels of β-glucan be developed. However, barley cultivars need to be developed that have lower fiber concentrations and higher ME values. This study examines these issues in feeding trials of 21 to 42 day-old broilers fed hulled and hulless barley diets. Diets comprised of 30% hulless or hulled barley, and a standard corn/soybean meal diet with and without β-glucanase enzyme were evaluated to determine the effects of barley on gut viscosity, carcass weight, gain, percent shell, and feed efficiency. Diets comprised of two hulless lines and the hulled cultivar Callao produced in 1998 and 1999 were compared to a standard check diet in two independent feeding trials. Each of the eight diets was fed to 20 broilers 21 to 42 days of age after which time they were processed. There was a significant (P#0.05) decrease in gut viscosity of birds fed diets with enzyme compared to birds fed diets without enzyme; however, gut viscosity did not affect weight gain or percent shell. Barley substituted at the 30% level did not have a significant effect on broiler performance, nor did the addition of enzyme. Absence of enzyme effect was attributed to bird age, since older birds are able to hydrolyze β-glucan more effectively (Bhatty, 1993). Since barley substituted at the 30% level in the diets of broilers did not cause any detrimental effects, addition of barley may potentially lead to a reduction in cost per pound of gain of broilers.

INTRODUCTION

The mid-Atlantic region is well situated regarding demands for feed grains in that poultry and swine operations provide domestic demand, and local export markets provide foreign demand. However, production of winter barley during the past few years has decreased mainly due to low market prices, even though the mid-Atlantic region is a feed grain deficient. Barley varieties with greater marketability in both domestic and foreign markets are needed to make barley an economical cash crop.

Although barley may be most commonly associated with beer production, approximately 73% of barley produced is used for livestock feed, while only 27% is used in malting and human consumption. Barley is an excellent source of highly digestible starch and protein for poultry, swine, and cattle. However, three of the most common problems associated with feeding barley to broiler chickens are high fiber concentration, low metabolizable energy (ME) value compared to corn, and relatively high concentration of anti-nutritive β-glucan.

Reports of barley ME have been widely variable in the literature. Some explanations for this variation are differences in condition of the grain, chemical composition, and experimental procedure used to analyze ME. Different tests have been used to analyze ME, including available metabolizable energy (AME), true metabolizable energy (TME), AME_n, and TME_n (corrected to nitrogen equilibrium); however, these tests have their disadvantages. AME is based on the relative proportion of carbohydrates, lipids, and proteins, while TME varies inversely with the amount of fiber present. As a result, barley that varies in these components is subject to altered ME calculations. In the literature, AME_n is used most commonly to express ME (Bhatty, 1993).

Standard ME recommendations of 2899 to 3301 kcal kg^{-1} have been set for poultry feed. The ME of barley generally does not exceed 2751 kcal kg^{-1}, while corn and wheat have average ME values of 3320 and 3250 kcal kg^{-1}, respectively (Bhatty, 1993). Therefore, traditional barley diets have been approximately 5 to 20% deficient in ME compared to wheat and corn. Contributing factors to low ME value are high fiber concentration, resulting in decreased feed intake, and high β-glucan concentration, which increases the viscosity of the intestinal fluid.

The concentration of β-glucan varies considerably depending on genotype and growing conditions. Extended periods of hot, dry weather just prior to harvest can greatly increase β-glucan concentration, which can range from 2 to 11% but usually averages 4 to 7%. Two-rowed barley generally contains a higher concentration of β-glucan than six-rowed barley (Bhatty, 1993).

Although the effects of β-glucan are not clear, it has been suggested that they interfere with the release of nutrients from the barley endosperm (Classen et al., 1985; Hesselman and Aman, 1986). Reports of food intake depression due to increased gut viscosity and slowing of feed passage have been documented (McNab and Smithard, 1992). A commonly held theory is that increased gut viscosity reduces the mixing of enzymes within the intestines and restricts available nutrients from contacting the intestinal walls for uptake (White et al., 1980). Sticky feces also was thought to be associated with increased gut viscosity, but later was found to be the result of microorganisms produced in the cecum in response to the presence of β-glucan, and not a direct result of the β-glucan itself. In order to reduce the concentration of cecal microorganisms in the intestines, addition of the enzyme β-glucanase to feed has proven beneficial (Bhatty, 1993).

Barley endosperm cell walls consist of 75% (1→3) and (1→4)-β-glucans, 20% arabinoxylan, and very small amounts of cellulose, glucomannan, phenolic acids, and protein. During the germination phase, the cell walls must be completely degraded in order to mobilize the starch and other stored nutrients. The scutellum is responsible for synthesizing β-glucanase which degrades the cell walls. Within the starchy endosperm, (1→3) and (1→4)-β-glucan concentrations are very high, and low energy fibrillar and cellulosic materials are present at very low concentrations. Conversely, the hull and other outer layers of barley grain consist of cell wall remnants in which cellulose, silica, and lignin contents are very high, and the (1→3) and (1→4)-β-glucan concentrations are very low.

Treatments employed to break down the β-glucan bonds in feed products include irradiation, wetting and drying treatments, and enzyme addition. The use of irradiation has not been very promising, and it is doubtful if any significant progress will be made in this area. Water treatments have had some measure of success; although, the mechanisms in this process are not fully understood. It is possible that the soaking period could cause an enzyme response in the grain, but it does not seem likely that it is associated with the degradation of β-glucans, since similar results have been reported in other grains (McNab and Smithard, 1992; Bamforth and Barclay, 1993). The most promising and feasible treatment is the addition of β-glucanase enzymes, that degrade the endosperm more thoroughly. More complete degradation of cell walls increases both available nutrients and nutrient uptake, and reduces viscosity in the cecum by reducing the amount of cecal microorganisms.

Broilers are generally fed a high-energy diet that promotes rapid growth and development, and thus diets high in barley have not been utilized. Studies of broiler chick diets have shown that hulled barley is inferior as a feed when compared to wheat and corn (Mannion, 1981; Hesselman et al., 1982; Newman and McGuire, 1985). However, Classen et al. (1985) reported that hulless barley had a higher TME than hulled barley, and when treated with β-glucanase had a TME very similar to wheat. Differences in available energy from hulless versus hulled barley have ranged from a high of 25 to 0% (Bhatty, 1993; Newman and Newman, 1988). Bhatty (1993) reported that addition of β-glucanase improves the ME of barley. In fact, most studies report positive effects on growth rate and digestibility with the addition of β-glucanase (White et al., 1980; Brenes et al., 1993; Salih et al., 1991; Almirall et al., 1995; Fuente et al., 1995; and Friesen et al., 1992). However, there can be large differences in response of cultivars to treatment with β-glucanase, the concentration of β-glucanase in the barley, and the activity of the β-glucanase used (Zhi-Yuan et al., 1995).

The two most practical remedies for the poor utilization of high-fiber barley in poultry diets is to develop high ME hulless barley coupled with the use of β-glucanase enzyme. Broiler chicks 1 to 20 days old generally have not performed well on diets high in barley, especially in the absence of enzyme supplementation (Rotter et al., 1990; Newman and Newman, 1988; Bhatty, 1993). However, less is known about the effects of hulless barley in the diets of broilers 21 to 42 days of age. This issue is of great interest in the highly-concentrated poultry-production area of the Mid-Atlantic region.

The objectives of this study are to examine the effects of: (i) hulless barley diets, and (ii) enzyme supplementation on the gut viscosity, feed efficiency, and carcass yield of broilers 21 to 42 days of age.

MATERIALS AND METHODS

Three experimental lines of hulless barley SC860972, SC890573, and SC880248, and the hulled cultivar Callao were used in broiler diets formulated with and without supplemental β-glucanase. The study was conducted for two years. Grain of Callao and hulless lines SC890573 and SC860972 produced in 1997-98 was used in the first trial, and grain of Callao and hulless lines SC890573 and SC880248 produced in 1998-99 was used in the second. Sufficient grain of SC860972 was not available in the second year. Diets comprised of 30% of the three hulless lines were compared to those of Callao at 30% with a standard corn/soybean meal based diet. All diets were fed to birds from 21-42 days of age.

In both years, the hulled barley cultivar Callao, and the hulless barley lines were grown in increase blocks near Warsaw, Virginia. Increase blocks were planted 22 October 1997. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 89.6, and 134.4 kg ha^{-1}, respectively, on 8 October. On 10 February, N was applied at a rate of 67.2 kg ha^{-1}. On 4 March 1998, octanoic acid ester of bromoxynil (herbicide) was applied at a rate of 38 g ha^{-1}. Nitrogen was applied at a rate of 56 kg ha^{-1} on 25 March. On 25 April, lambda-cyhalothrin was applied at a rate of 19 g ha^{-1} for the control of cereal leaf beetle. Plots were harvested on 8 June 1998. In 1998-99, blocks were planted 19 October. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 33.6, and 112 kg ha^{-1}, respectively, on 5 October. On 5 December 1998 Thifensulfuron (herbicide) and nitrogen were applied at rates of 14.03 g ha^{-1} and 22.4 kg ha^{-1}, respectively, with a boom sprayer. On 1 February 1999, nitrogen was applied at a rate of 33.6 kg ha^{-1}. On 30 March, nitrogen was applied at a rate of 67.2 kg ha^{-1}. Lambda-cyhalothrin was applied at a rate of 19 g ha^{-1} for the control of cereal leaf beetle on 6 May 1999. Plots were harvested on 3 June 1999.

The feeding trial was designed as a Randomized Complete Block comprised of eight treatments with four replications per treatment and five male broilers per replication. A 2 by 4 factorial arrangement of treatments included four types of grain (Corn/soybean meal (SBM), hulled barley cultivar Callao, and hulless lines SC890573 and SC860972 or SC880248 depending on year), and two concentrations of supplemental β-glucanase (0 and 0.1%) (Table 1). The β-glucanase (Avizmye®) was obtained from Finn Feeds, Marlborough, Wiltshire, United Kingdom.

Approximately 500 one-day old male commercial broilers were purchased from Mountaire and reared in pens until 21 days of age. Birds were vaccinated in-ovo for Marek s at 18 days of age and spray vaccinated (IBV and Newcastle) at one day of age. Standard broiler starter (0-21 days) and grower (21-42 days) basal rations were formulated to meet or exceed National Research Council (NRC) requirements. The kcal kg^{-1} to % crude protein (CP) ratio (3200/20) was that recommended by the NRC and the ME value of the diets was 3200 kcal kg^{-1}.

Birds were fed starter feed until 21 days of age. After an overnight fast, birds were weighed on day 21 and a homogenous group of 160 birds was selected for allotment to treatments. Birds were allotted to treatments in a manner to insure a similar average weight and weight range for all 32 pens in the trial.

Birds were fed their respective diets from 21 to 42 days of age. Feed and water were offered *ad libitum*. Heating, lighting and ventilation were in accordance to recommended practices. Birds were weighed and slaughtered at 42 days of age. The intestinal contents (post-duodenum to Merke s diverticulum) were collected from each bird and combined by pen, and gut viscosity determined using a Brookfield¤ viscometer. The dependent variables assessed were gut viscosity, feed consumption, live weight, carcass weight, percent shell [(eviscerated carcass weight/live weight) x 100], weight gain, and feed efficiency (eviscerated shell weight/feed consumption).

Grain nutrient analyses of Callao and the three hulless barley lines were conducted to determine TME_n, and the concentrations of fiber, β-glucan, protein, and fat. New Jersey Feed Laboratory, Inc., Trenton New Jersey, determined the fiber content, while Ingman Laboratories, Inc., Minneapolis, MN determined the β-glucan content. The University of Georgia, Cooperative Extension Service, College of Agriculture and

Environmental Sciences, Athens Georgia conducted a live bird assay to determine the TME_n.

Data Analysis

Data from both years were analyzed by analysis of variance using SAS software (SAS Inst., 1999). The general linear model (GLM) procedure was employed, and effect of replication, pen, diet, enzyme and all interactions were tested; however, only within-year data comparisons were made due to significant year effects (Table 2). Using the Tukey test, mean separations were performed on all diet and enzyme combinations where the ANOVA F-statistic indicated significant interaction effects at the 0.05 level (SAS Inst., 1999).

RESULTS AND DISCUSSION

The addition of enzyme to barley-based diets significantly reduced gut viscosity in birds in 1998 (Table 3). Birds fed hulless barley-based diet comprised of SC880248 in 1999 also exhibited a decrease in gut viscosity with addition of enzyme (Table 4). However gut viscosity of birds fed Callao and SC890573 with enzyme was not significantly lower than those fed the same diets without enzyme in 1999. Although this was unexpected, there was a trend toward lower gut viscosity in birds fed these two barley-based diets with enzyme compared to those fed the same diets without enzyme. These findings support those of Salih et al. (1991), who reported a gut viscosity of 2.36 for birds fed hulless barley without enzyme compared to a gut viscosity of 1.53 for birds fed hulless barley with enzyme (Table 5). These results indicate that fiber concentration does not play a major role in gut viscosity since birds fed Callao, which contains a significantly higher concentration of fiber (Table 6), did not differ in gut viscosity compared to those fed hulless lines SC890573, SC860972 and SC80248 in 1998 or 1999.

The addition of enzyme to the corn/soybean meal diets did not significantly ($P>0.05$) affect the performance of birds in any of the parameters measured in 1998 or 1999. Since commercial broilers are fed corn/soybean meal diets without the addition of enzyme while barley-based diets fed to commercial broilers contain enzyme, it is logical to make comparisons in this study between the corn/soybean meal diet without enzyme versus barley-based diets with enzyme.

In 1998 feed consumption was higher for birds fed diets comprised of SC890573 with enzyme compared to those fed diets of corn/soybean meal, while feed consumption of birds fed diets of SC860972 and Callao did not differ from those fed corn/soybean meal (Table 3). However in 1999, feed consumption of birds fed diets comprised of Callao, SC890573, and SC880248 did not differ from those fed corn/soybean meal (Table 4). Results show no difference in consumption between corn/soybean meal and barley-based diets, which supports findings by Friesen et al. (1992), who reported no significant difference in feed consumed by broilers fed diets comprised of 35% hulled or hulless barley (Table 5).

Live weight of birds fed diets of SC890573 with enzyme was higher than those fed corn/soybean meal or Callao diets, while birds fed SC860972 did not differ in live weight from those fed the other diets in 1998. Live weights in 1999 were not affected greatly by diet. However, differences in live weight are not the only parameter of concern, since performance of birds can be accurately measured by other parameters such as percent shell.

Carcass weight of birds fed SC890573 with enzyme was higher than those fed corn/soybean meal or Callao, while those fed SC860972 did not differ from those of any other diet in 1998. However, there was a trend toward increased carcass weight among birds fed hulless diets with enzyme, while those fed Callao tended to be unaffected by enzyme. Carcass weight in 1999 did not differ among diets.

Similarly, weight gain of birds fed SC890573 with enzyme was higher than those fed corn/soybean meal or Callao, while weight gain of birds fed SC860972 did not differ from those of other diets in 1998. Weight gain in 1999 did not differ among diets. The effect of enzyme on weight gain in broiler chicks has been met with conflicting reports in the literature. Friesen et al. (1992) reported no difference in weight gain when comparing broiler chicks fed hulled and hulless barley with and without enzyme starting at seven days of age. However, Newman and Newman (1988) reported that broiler chicks fed hulled and hulless barley with enzyme, starting at three days of age, gained more weight than those fed hulled and hulless barley without enzyme. Several factors can affect performance of birds, including environmental conditions, cultivar or line of barley, phenotype of barley (two rowed or six rowed; spring or winter), and time between harvest and feeding (Bhatty, 1993).

In 1998, birds fed SC890573 and SC860972 with enzyme were significantly (P#0.05) more feed efficient than those fed hulless barley without enzyme or those fed Callao with enzyme. Analysis of the data indicated a trend toward increased efficiency of birds fed hulless lines with enzyme compared to those fed Callao with or without enzyme. In 1999, birds did not differ in feed efficiency. Friesen et al. (1992), Salih et al. (1991), and Newman and Newman (1988) also reported no difference in feed efficiency among broiler chicks fed hulled and hulless barley with and without enzyme. Examination of their respective data indicate that a trend exists toward increasing feed efficiency with addition of enzyme. Zhi-Yuan et al. (1995) reported similar feed efficiency of broiler chicks fed hulless barley without enzyme. A trend toward increased feed efficiency may be explained in part by a trend toward increasing ME values of hulled and hulless barley with the addition of enzyme (Friesen et al., 1992; Fuente et al., 1995).

Percent shell [(live weight/carcass weight) x 100] in 1998 was lower for birds fed Callao with enzyme than those fed SC860972 with enzyme, while percent shell of birds fed corn/soybean meal and SC890573 diets did not differ from those fed Callao or SC860972. Percent shell did not differ greatly between bird fed differing diets in 1999. Shell efficiency in 1998 was higher for birds fed SC860972 without enzyme than those fed Callao and SC890573 with enzyme. The rest of the birds fed the different diets did not differ significantly in shell efficiency. In 1999, shell efficiency was significantly higher for birds fed Callao with enzyme than without, and higher for those fed SC890573 without than with enzyme.

In 1998, broilers fed hulless line SC890573 with enzyme had higher feed consumption, live weight, carcass weight, weight gain, and higher feed efficiency than those in 1999. Birds fed Callao without enzyme in 1999 tended to consume less than those fed Callao with enzyme, but tended to have higher live weight, carcass weight, and weight gain.

Among the parameters feed efficiency, percent shell, and shell efficiency, broilers fed hulled and hulless barley did not differ significantly (P>0.05) from those fed corn/soybean meal diets. It can be concluded that in this study, broilers fed hulled or hulless barley are not adversely affected compared to those fed corn/soybean meal diets.

In 1998, all parameters measured, except percent shell, were significantly higher for broilers fed SC890573 with enzyme. However, no difference was observed in 1999. Since percent shell is a measure of efficiency and actual performance and no difference was observed in either year, performance of SC890573 was not superior to the other diets. In fact, results indicated that a trend for increased performance was more likely for SC860972 than for SC890573. Some differences in performance may be explained by differing condition of grain over years. However, since birds fed barley-based diets did not differ from those fed corn/soybean meal diets it can be concluded that Callao barley or hulless lines may be substituted for corn/soybean meal at the 30% level with no adverse effects on performance in the presence of enzyme. These findings support those of Friesen et al. (1992) who found similar results when substituting diets with 35% barley.

Substitution of corn/soybean meal with hulless barley in the diets of poultry has several advantages. The hulless barley lines evaluated in the present study have a protein concentration of approximately 3% greater than that of corn, which is of significance in balancing and formulating rations. There is also a trend toward lower prices per unit barley than that of corn. Also since the mid-Atlantic region is a corn deficient area, local barley would have a price advantage over that of corn shipped in from other regions. However, such factors as cost of enzyme and handling of an additional grain must be examined in order to determine true cost advantage of hulless barley over corn.

CONCLUSIONS

Callao hulled barley, and SC860972, SC880248, and SC890573 hulless barley can be substituted at a 30% level of the total corn/soybean meal diet with no adverse effects on performance in 21 to 42 day old broilers. Such substitution holds potential to reduce cost per unit gain in broiler production through a reduction in feed cost. In addition, as lines with higher nutritive value are developed for the mid-Atlantic region, it is likely that improved performance will be observed in broilers fed these lines. Hulless barley therefore has potential to surpass Callao as a feed for broilers and possibly can be substituted in greater amounts in diets of broilers.

The hulless barley examined in this study maintained an average ME (2909 kcal kg^{-1}) above the minimum recommendation of the NRC (2899 kcal kg^{-1}). This allows the amount of costly high-energy additives to be reduced when formulating poultry rations from hulless barley. Also, since fiber levels of hulless barley are significantly lower than those of hulled barley, hulless barley is able to be treated more like wheat in ration formulation. Effects of β-glucan have been minimized with the use of β-glucanase, although no significant effect from addition of enzyme was seen on shell or feed efficiency in this study. However, enzyme still plays an important role in younger birds, and in that of birds that receive a higher level of barley in their diets. As more time and resources are devoted to the development of hulless barley in the mid-Atlantic region, it is likely that lines higher in energy and protein will be developed. Further research will need to be conducted as these new hulless lines are developed.

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TABLES

Table 1. Composition of five diets formulated for evaluation of hulled and hulless barley with and without β-glucanase fed to 21 to 42 day old broilers.

	Diets[1]				
Ingredients	CSB[2]	SC890573[3]	SC860972[3]	SC880248[3]	Callao[4]
	(g kg^{-1} diet)				
Hulless barley	0	300.0	300.0	300.0	0
Hulled barley	0	0	0	0	300.0
Corn	624.0	339.6	339.6	339.6	339.6
Soybean meal	310.0	282.4	282.4	282.4	282.4
Corn Oil	36.8	49.7	49.7	49.7	49.7
Defluor. Phos.	11.8	11.9	11.9	11.9	11.9
Limestone	11.2	11.1	11.1	11.1	11.1
Common Salt	1.8	1.7	1.7	1.7	1.7
DL-Methionine	1.4	1.6	1.6	1.6	1.6
Bio-Cox® coccidiostat	1.0	1.0	1.0	1.0	1.0
Vitamin Premix[5]	0.5	0.5	0.5	0.5	0.5
Mineral Premix[6]	0.5	0.5	0.5	0.5	0.5
L-Lysine HCL	0.1	0	0	0	0
	1000.0	1000.0	1000.0	1000.0	1000.0
Calculated Analysis:					
CP[7] (%)	23.0	23.0	23.0	23.0	23.0
ME[8] (kcal kg$^{-1)}$	3200.0	3200.0	3200.0	3200.0	3200.0
Tryptophan	0.29	0.24	0.24	0.24	0.24
Threonine	0.93	0.81	0.81	0.81	0.81

[1]All diets fed with and without β-glucanase enzyme.
[2]Corn/soybean meal.
[3]Hulless barley lines
[4]Hulled barley cultivar.
[5]Supplies per kg diet: 0.1 mg Se, 5500 I.U. Vitamin A, 2200I.C.U. Vitamin D_3, 4.4 I.U. Vitamin E, 1.5 mg Vitamin K, 6.6 mg Riboflavin, 33 mg Niacin, 11 mg Pantothenic acid, 1.1 mg Pyridoxine, 220 Φg Folacin, 13 Φg Vitamin B_{12}, and 27.5 mg ethoxyquin.
[6]Supplies per kg diet: 75 mg Mn as MnO, 60 mg Zn as ZnO, 20 mg Fe as $FeSO_4$, 3 mg Cu as CuO and 0.75 mg I as $Ca(IO_3)_2$.
[7]Crude Protein.
[8]Metabolizable Energy.

Table 2. Main and interaction effects of diet and enzyme on 21 to 42 day-old broilers in 1998 and 1999.

	Gut Viscosity	Feed Consumption	Live Weight	Carcass Weight[1]	Weight Gain	Percent Shell[2]	Feed Efficiency[3]
Year	0.7364[4]	<.0001	<.0001	<.0001	0.0020	0.0003	<.0001
Diet[5]	<.0001	0.1238	0.7397	0.9581	0.7412	0.0216	0.7943
Enzyme[6]	<.0001	0.2355	0.0838	0.0893	0.0856	0.1971	0.7366
Diet*Enzyme	0.0009	0.2487	0.4026	0.4525	0.4137	0.9059	0.7492

[1] Eviscerated carcass.
[2] Carcass weight / live weight x 100.
[3] Weight gain / feed consumption.
[4] Probability values, Proc. Corr. SAS, 1999.
[5] Four diets fed; 1=corn soybean meal, 2=corn soybean meal and 30% hulled barley, and 3 and 4= corn soybean meal and 30% hulless barley
[6] β-glucanase enzyme Avizyme®, fed at 0 and 0.1%, Finn Feeds, Marlborough, Wiltshire, United Kingdom.

Table 3. Poultry feeding trial of three corn/soybean meal diets formulated with 30% Callao hulled barley and two hulless barley lines, respectively, compared to a standard 100% corn soybean meal diet in 1998.

Diet	Enzyme[1]	Gut Viscosity	Feed Consumption	Live Weight.	Shell Weight[2]	Weight Gain	Feed Efficiency[3]	Percent Shell[4]	Shell Efficiency[5]
			g						
100% Corn/SBM[6]	-	2.46[c][7]	1244.9[bc]	1921.1[b]	1271.0[bc]	605.8[b]	0.49[ab]	66.2[ab]	1.02[abc]
	+	2.97[c]	1244.8[bc]	1972.5[ab]	1323.0[abc]	632.2[ab]	0.51[a]	67.0[ab]	1.06[ab]
30% Callao[8]	-	5.31[b]	1304.3[abc]	1928.3[ab]	1269.7[bc]	609.3[ab]	0.47[abc]	65.8[ab]	0.97[abc]
	+	3.07[c]	1335.4[ab]	1912.3[b]	1249.5[bc]	601.7[b]	0.45[bc]	65.4[b]	0.94[bc]
30% SC890573[9]	-	6.68[a]	1246.2[bc]	1812.0[b]	1186.3[c]	551.5[b]	0.44[c]	66.0[b]	0.95[abc]
	+	3.11[c]	1380.5[a]	2115.3[a]	1414.0[a]	703.3[a]	0.51[a]	66.8[ab]	1.02[c]
30% SC860972[9]	-	5.87[ab]	1199.3[c]	1867.3[b]	1245.1[bc]	579.5[b]	0.48[abc]	66.6[ab]	1.04[a]
	+	3.04[c]	1276.7[abc]	1991.5[ab]	1343.3[ab]	640.1[ab]	0.50[a]	67.5[a]	1.05[abc]

[1]β-glucanase enzyme Avizyme®, fed at 0 and 0.1%, Finn Feeds, Marlborough, Wiltshire, United Kingdom.
[2]Eviscerated carcass.
[3]Weight gain / feed consumption (higher values indicate higher efficiency).
[4]Carcass weight / live weight x 100.
[5]Shell weight / feed consumption (higher values indicate higher efficiency).
[6]SBM = soybean meal.
[7]Means followed by the same letter are not significantly different based on Tukey test (P#0.05).
[8]Hulled barley cultivar substituted at the 30% level for corn.
[9]Hulless barley lines substituted at the 30% level for corn.

Table 4. Poultry feeding trial of three corn/soybean meal diets formulated with 30% Callao hulled barley and two hulless barley lines, respectively, compared to a standard 100% corn soybean meal diet in 1999.

Diet	Enzyme[1]	Gut Viscosity	Feed Consumption	Live Weight.	Shell Weight[2]	Weight Gain	Feed Efficiency[3]	Percent Shell[4]	Shell Efficiency[5]
			g						
100% Corn/SBM[6]	-	2.64[c6]	1414.5[b]	1706.9[ab]	1125.6[ab]	555.3[ab]	0.39[bc]	65.9[ab]	0.80[a]
	+	2.93[c]	1432.5[ab]	1595.8[b]	1053.7[b]	499.9[b]	0.35[c]	66.0[a]	0.74[a]
30% Callao[8]	-	5.26[abc]	1500.9[a]	1774.9[a]	1150.3[ab]	589.4[a]	0.39[bc]	64.8[b]	0.77[b]
	+	3.54[bc]	1418.9[ab]	1807.3[a]	1179.8[a]	605.5[a]	0.43[b]	65.3[ab]	0.83[a]
30% SC890573[9]	-	6.21[ab]	1419.7[ab]	1694.2[ab]	1110.3[ab]	549.2[ab]	0.39[bc]	65.6[ab]	0.78[a]
	+	3.62[bc]	1445.1[ab]	1657.9[ab]	1075.5[ab]	530.8[ab]	0.37[bc]	64.8[ab]	0.74[b]
30% SC860972[9]	-	6.42[a]	1457.2[ab]	1704.5[ab]	1107.7[ab]	554.1[ab]	0.38[bc]	65.0[ab]	0.76[ab]
	+	2.81[c]	1438.0[ab]	1778.1[a]	1162.2[ab]	591.0[a]	0.41[bc]	65.3[ab]	0.81[ab]

[1]β-glucanase enzyme Avizyme®, fed at 0 and 0.1%, Finn Feeds, Marlborough, Wiltshire, United Kingdom.
[2]Eviscerated carcass.
[3]Weight gain / feed consumption (higher values indicate higher efficiency).
[4]Carcass weight / live weight x 100.
[5]Shell weight / feed consumption (higher values indicate higher efficiency).
[6]SBM = soybean meal.
[7]Means followed by the same letter are not significantly different based on Tukey test (P#0.05).
[8]Hulled barley cultivar substituted at the 30% level for corn.
[9]Hulless barley lines substituted at the 30% level for corn.

Table 5. Related data from previous studies comparing hulled and hulless barley, and corn in diets of broilers.

Author	Feed		Gut Viscosity		Weight Gain		Feed Consumption		Feed Efficiency[1]		AME[2]	
			Enzyme								Enzyme	
	Barley	Diet	no	yes	no	yes	no	yes			no	yes
		—%—			g				g/g		kcal kg^{-1}	
Friesen et al. (1992)	Hulless	35			138	138	205	189	.67	0.73	3164	3552
	Hulled	35			138	143	198	200	0.69	0.71	3313	3506
Newman and Newman (1988)	Hulled	57			657	688			0.62	0.64		
	Hulless	57			670	708			0.62	0.66		
Classen et al. (1985)	Hulless	0			464				0.60			
		20			446				0.61			
		40			416				0.56			
		60			404				0.60			
Zhi-Yuan et al. (1995)	Hulless	75			620				0.64			
	Hulless	75			625				0.63			
Fuente et al. (1995)	Hulless	30									3310	3324
		40									3227	3322
		50									3179	3286
		60									3157	3179
Salih et al. (1991)	Hulless	60	2.36	1.53	791	842			0.50	0.53	3097	
Rotter et al. (1990)	Hulled	25	2.18								2925	
	Hulled	50	2.94								2997	
	Hulless	25	1.98								2658	
	Hulless	50	6.81									

[1]Weight gain/Feed consumption
[2]Actual Metabolizable Energy

CONCLUSIONS AND
FUTURE RESEARCH

The results of part one of this study indicate that hulless winter barley has great potential as a dependable, competitive grain crop in the mid-Atlantic region. However, this will require development of improved hulless winter barley lines through breeding. Development of hulless lines with yield potential equal to that of soft red winter wheat should be feasible. Test weights of the hulless lines evaluated proved to be very similar to those of wheat, and superior to that of hulled barley. Other agronomic traits of hulless barley did not tend to differ from those of the hulled barley cultivars currently grown in the region. In addition, use of hulless accessions from the world collection in breeding programs likely will provide sources of genetic improvement for adapted winter hulless lines.

Part two of the study indicated that barley could be substituted in the diets of 21 to 42 day old broilers with no adverse affects on performance. With the substitution of barley for corn and soybean meal, a reduction in the cost per unit gain could be realized. In addition, as more adapted hulless lines are developed for the mid-Atlantic region, it is likely that improved performance will be observed in broilers fed theses lines. Hulless barley therefore has potential to surpass Callao as a feed for broilers and likely can be substituted in greater amounts in diets of broilers.

Hulless barley can compete with hulled barley very effectively by offering lower fiber concentration and higher protein concentration. Hulless barley is also competitive with wheat by allowing double-crop soybeans to be planted ten days earlier, while having similar test weight and similar handling and storage. In the mid-Atlantic region, when compared to corn, hulless barley offers production dependability, and when coupled with double-crop soybeans provides an economically competitive crop scheme.

Hulless barley also offers producers and the poultry and swine industries a product with ease of handling. Hulled barley occupies 50% more space compared to hulless barley, and 10 to 13% of the weight of hulled barley is the hull. Therefore by growing and feeding hulless barley, hauling, storage, and feed cost per unit of energy will be lower. In this regard it is very similar to wheat while offering increased fat concentrations.

With sufficient time and resources, yield of hulless winter barley genotypes can be increased over that of existing unadapted lines through traditional breeding methods.

As new high-yielding, desirable hulless lines are developed, further feeding studies will need to be conducted to determine the role of winter hulless barley in the mid-Atlantic region.

APPENDIX A

PLOT MANAGEMENT

Yield plots were managed in slightly different ways with regard to timing and amounts of chemicals and fertilizers applied. The number of rows, and plot width and length also varied according to state and location (Table 1A). The following information is a detailed account of how each location was managed within each year.

1996-1997

Virginia

At Blacksburg, plots were planted 12 October 1996. Preplant N, P_2O_5, and K_2O was applied at a rate of 28, 67, and 89.6 kg ha^{-1}, respectively, on 25 September. On 7 March 1997 Thifensulfuron, Nitrogen, and Sulfur were applied at rates of 17.54 g ha^{-1}, 67.2 kg ha^{-1}, and 14.56 kg ha^{-1}, respectively, with a boom sprayer. Plots were harvested on 26 June and 9 July 1997 for barley and wheat tests, respectively.

At Orange plots were planted 15 October 1996. Preplant N, P_2O_5, and K_2O was applied at a rate of 39.2, 78.4, and 78.4 kg ha^{-1}, respectively, on 14 October. On 7 March 1997, Thifensulfuron and fertilizer were applied at rates of 17.54 g ha^{-1} and 67.2 kg ha^{-1} N, respectively, with a boom sprayer. Plots were harvested on 11 and 26 June 1997 for barley and wheat tests, respectively.

At Painter plots were planted 28 October 1996. Preplant N, P_2O_5, and K_2O was applied at a rate of 28, 56, and 56 kg ha^{-1}, respectively, on 17 October. Nitrogen, at a rate of 44.8 kg ha^{-1} was applied 20 February 1997. On 26 March 1997 Thifensulfuron and fertilizer was applied at a rate of 17.54 g ha^{-1} and 67.2 kg ha^{-1} N, respectively, with a boom sprayer. Plots were harvested on 20 and 24 June 1997 for barley and wheat tests, respectively.

At Warsaw plots were planted 16 October 1996. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 67.2, and 67.2 kg ha^{-1}, respectively, on 7 October. On 19 February 1997 Thifensulfuron was applied at a rate of 17.54 g ha^{-1} on wheat plots, and

6.72 g ha^{-1} on barley plots, and nitrogen and sulfur were applied at rates of 56.0 kg ha^{-1} and 8.06 kg ha^{-1} on all plots with a boom sprayer. Nitrogen and sulfur were again applied to barley and wheat plots at a rate of 50.4 g ha^{-1} and 6.05 g ha^{-1} on 25 March 1997. Two oz of octanoic acid ester of bromoxynil (herbicide) was applied on 18 May 1997. Plots were harvested on 11 and 24 June 1997 for barley and wheat tests, respectively.

North Carolina

At Kinston all plots were planted 17 October 1996. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 67.2, and 67.2 kg ha^{-1}, respectively, on 1 October. Nitrogen was applied on 19 February 1997, at a rate of 123.2 kg ha^{-1}, and on 19 February 1997, Thifensulfuron was applied at a rate of 14.03 g ha^{-1} with a boom sprayer. Plots were harvested on 22 May 1997.

At Rowan all plots were planted 15 October 1996. Preplant N, P_2O_5, and K_2O was applied at a rate of 34.7, 89.6, and 0 kg ha^{-1}, respectively, on 14 October. On 2 February 1997 Thifensulfuron and Nitrogen was applied at a rate of 14.03 g ha^{-1} and 50.4 kg ha^{-1}, respectively, with a boom sprayer. On 12 March, nitrogen was applied again at a rate of 33.6 kg ha^{-1}. Plots were harvested on 13 June 1997.

Kentucky

At Lexington all plots were planted 17 October, 1996. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 67.2, and 67.2 kg ha^{-1}, respectively, on 1 October. Nitrogen was applied on 19 February 1997, at a rate of 44.8 kg ha^{-1}, and on 19 February 1997, Thifensulfuron was applied at a rate of 14.03 g ha^{-1} with a boom sprayer. Plots were harvested on 22 May 1997.

Maryland

At Keedysville, plots were planted 27 September 1996. Preplant N, P_2O_5, and K_2O was applied at a rate of 16.8 kg ha^{-1}, respectively, on 26 September. On 10 March, 1997 Thifensulfuron was applied at a rate of 14.03 g ha^{-1}, and N, P_2O_5, and K_2O were each applied at a rate of 44.8 kg ha^{-1}, respectively, with a boom sprayer. Plots were harvested on 23 June and 15 July 1997 for barley and wheat tests, respectively.

1997-1998

Virginia

At Blacksburg plots were planted 6 and 7 October 1997 for barley and wheat tests, respectively. Preplant N, P_2O_5, and K_2O was applied at a rate of 28, 56, and 100.8 kg ha^{-1}, respectively, on 3 October. On 7 March, 1997 Thifensulfuron was applied at a rate of 17.54 g ha^{-1} and nitrogen and sulfur applied at rates of 67.2 and 7.84 kg ha^{-1} with a boom sprayer. Plots were harvested on 16 June and 1 July, 1997 for barley and wheat tests, respectively.

At Orange plots were planted 9 October 1997. Preplant N, P_2O_5, and K_2O was applied at a rate of 28, 56, and 67.2 kg ha^{-1}, respectively, on 8 September. Thifensulfuron was applied on 3 December 1997 at a rate of 17.54 g ha^{-1}. On 27 March 1997 nitrogen was applied at a rate of 67.2 kg ha^{-1} with a boom sprayer. Plots were harvested on 9 June and 24 and 25 June 1997 for barley and wheat tests, respectively.

At Painter plots were planted 31 October 1997. Preplant N, P_2O_5, and K_2O was applied at a rate of 28, 56, and 56 kg ha^{-1}, respectively, on 30 October. Nitrogen was applied at a rate of 44.8 kg ha^{-1} on 20 February 1997. On 3 March, 1997 Thifensulfuron and nitrogen were applied at a rate of 17.54 g ha^{-1} and 100.8 kg ha^{-1}, respectively, with a boom sprayer. Plots were harvested on 18 and 19 June 1997 for barley and wheat tests, respectively.

At Warsaw plots were planted 22 October 1997. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 89.6, and 134.4 kg ha^{-1}, respectively, on 8 October. On 10 February, 67.2 kg ha^{-1} N was applied. On 4 March 1998, octanoic acid ester of bromoxynil (herbicide) was applied at a rate of 38 g ha^{-1}. Nitrogen was applied at a rate of 56 kg ha^{-1} on 25 March (GS 30). Nitrogen was applied at a rate of 56 and 67.2 kg ha^{-1}, respectively, for barley and wheat plots on 25 March. On 25 April, 19 g ha^{-1} lambda-cyhalothrin was applied for the control of cereal leaf beetle. Plots were harvested on 8 and 18 June 1998 for barley and wheat tests, respectively.

North Carolina

At Kinston all plots were planted 19 October 1997. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 67.2, and 67.2 kg ha^{-1}, respectively, on 8 October. Nitrogen and Thifensulfuron was applied on 16 February 1998, at a rate of 134.4 kg ha^{-1} and 14.03 g ha^{-1}, respectively, with a boom sprayer. Plots were harvested on 21 May 1998.

At Rowan all plots were planted 13 October 1997. Preplant N, P_2O_5, and K_2O was applied at a rate of 34.7, 89.6, and 0 kg ha^{-1}, respectively, on 12 October. On 2 February 1998 Thifensulfuron and nitrogen was applied at a rate of 14.03 g ha^{-1} and 50.4 kg ha^{-1}, respectively, with a boom sprayer. On 12 March, nitrogen was applied again at a rate of 33.6 kg ha^{-1}. Plots were harvested on 10 June 1998.

Kentucky

At Lexington all plots were planted 17 October 1997. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 67.2, and 67.2 kg ha^{-1}, respectively, on 1 October. Nitrogen was applied on 19 February 1997, at a rate of 44.8 kg ha^{-1}, and on 19 February 1998, Thifensulfuron was applied at a rate of 14.03 g ha^{-1} with a boom sprayer. Plots were harvested on 22 May 1998.

Maryland

At Keedysville, plots were planted 27 September 1997. Preplant N, P_2O_5, and K_2O was applied at a rate of 16.8 kg ha^{-1}, respectively, on 26 September. On 7 March 1998 Thifensulfuron, was applied at a rate of 14.03 g ha^{-1}, and N, P_2O_5, and K_2O was applied at a rate of 44.8 kg ha^{-1}, respectively, with a boom sprayer. Plots were harvested on 23 June and 15 July 1998 for barley and wheat tests, respectively.

1998-1999

Virginia

At Blacksburg barley and wheat plots were planted 14 and 15 October 1998, respectively. Preplant N, P_2O_5, and K_2O was applied at a rate of 28, 112, and 112 kg ha^{-1}, respectively, on 6 October. On 11 February 1997 Thifensulfuron was applied at a rate of 17.54 g ha^{-1} with a boom sprayer. On 31 March 1997 Thifensulfuron and nitrogen were applied at a rate of 17.54 g ha^{-1} and 67.2 kg ha^{-1}, respectively, with a boom sprayer. Plots were harvested on 18 June and 4 July 1999 for barley and wheat tests, respectively.

At Orange plots were planted 15 October 1998. Preplant N, P_2O_5, and K_2O was applied at a rate of 28.0, 56.0, and 56.0 kg ha^{-1}, respectively, on 14 September. On 1 February 1999 Thifensulfuron was applied at a rate of 17.54 g ha^{-1}. On 26 February nitrogen was applied at a rate of 67.2 kg ha^{-1} with a boom sprayer. Plots were harvested on 4 June 1999.

At Painter plots were planted 21 October 1998. Preplant N, P_2O_5, and K_2O was applied at a rate of 28.0, 56.0, and 56.0 kg ha^{-1}, respectively, on 20 October. Dolomitic limestone was applied at a rate of 2.24 t ha^{-1} on 21 October 1998. On 3 March 1999 Thifensulfuron and nitrogen were applied at rates of 17.54 g ha^{-1} and 112 kg ha^{-1}, respectively, with a boom sprayer. Plots were harvested on 7 and 8, and 24 June 1999 for barley and wheat tests, respectively.

At Warsaw plots were planted 19 and 20 October 1998. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 33.6, and 112 kg ha^{-1}, respectively, on 5 October. On 5 December 1998 Thifensulfuron and nitrogen were applied at rates of 14.03 g ha^{-1} and 22.4 kg ha^{-1}, respectively, with a boom sprayer. On 1 February 1999, nitrogen was applied at a rate of 33.6 kg ha^{-1}. On 30 March, nitrogen was applied at a rate of 67.2 kg ha^{-1}. On 6 May 1999, 19 g ha^{-1} lambda-cyhalothrin was applied for the control of cereal leaf beetle. Plots were harvested on 3 and 24 June 1999 for barley and wheat tests, respectively.

North Carolina

At Kinston all plots were planted 20 October 1998. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 67.2, and 67.2 kg ha^{-1}, respectively, on 29 September. Nitrogen was applied on 9 February 1999 at a rate of 33.6 kg ha^{-1}, and on 10 February

1999, Thifensulfuron was applied at a rate of 14.03 g ha^{-1} with a boom sprayer. Plots were harvested on 18 May 1997.

At Rowan all plots were planted 17 October 1998. Preplant N, P_2O_5, and K_2O was applied at a rate of 34.7, 89.6, and 0 kg ha^{-1}, respectively, on 16 October. On 2 February 1999 Thifensulfuron and Nitrogen was applied at a rate of 14.03 g ha^{-1} and 50.4 kg ha^{-1}, respectively, with a boom sprayer. On 12 March, nitrogen was applied again at a rate of 33.6 kg ha^{-1}. Plots were harvested on 12 June 1999.

Kentucky

At Lexington all plots were planted 17 October 1998. Preplant N, P_2O_5, and K_2O was applied at a rate of 33.6, 67.2, and 67.2 kg ha^{-1}, respectively, on 1 October. Nitrogen was applied on 19 February 1997, at a rate of 44.8 kg ha^{-1}, and on 19 February 1999, Thifensulfuron was applied at a rate of 14.03 g ha^{-1} with a boom sprayer. Plots were harvested on 22 May 1999.

Maryland

At Keedysville, plots were planted 7 October 1998. On 10 March 1999 Thifensulfuron and nitrogen was applied at a rate of 17.54 g ha^{-1}, and 44.8 kg ha^{-1}, respectively, with a boom sprayer. Plots were harvested on 16 and 30 June 1999 for barley and wheat tests, respectively.

TABLES

Table A-1. Plot dimensions of the four participating states for tests of hulled and hulless barley, Trical 498 triticale, and Jackson wheat.

State	Rows	Spacing	Length	Width	Area
	—no.—	— cm —	— m—	— m —	m^2
Virginia	7	15.24	2.74	1.07	2.93
North Carolina	7	17.78	3.04	1.24	3.77
Kentucky	6	17.78	3.04	1.07	3.25
Maryland	6	15.24	3.04	0.91	2.77

Table A-2. Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype name or designation[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
1	PI	6597	Hankow	China	1	2	104	2	MS	4	0;
2	PI	19895	Yane Hadaka	Japan	1	2	107	2	S	4	;1=
3	PI	21669	Me Mesh	China	1	3	107	2	MR-I	4	2
4	PI	264457	Zun Paku Mugi	Japan	1	2	107	1	MS	23C	12
5	PI	26459	Kama-ore	Japan	3	3	106	2	I	4	12
6	CIho	703	Hansee Hull-less	USA	1	3	104	2	S	4	0;
7	PI	31764	Kharsila	India	3	3	98	2	MR	4	12
8	PI	32485	Mi Ta Meh	China	1	2	105	2	I	4	;12
9	PI	34129	Taihu	China	1	2	104	2	I	4	;2
10	PI	39365	Eremo	India	3	2	100	1	R	4	234
11	PI	41153	Irisaka	Pakistan	8	2	100	2	MRR	4	0;N
12	PI	41156	Dehra	India	1	2	102	1	R	4	;1
13	PI	41162	Gopal	India	8	2	102	2	MRR	4	;12
14	CIho	1373	Purple Nepal	USA	7	1	109	0	MRI	4	;1N
15	CIho	1374	Takeshita	Japan	1	2	108	1	MSI	23C	234
16	CIho	2239	Eremo	India	4	2	100	1	R	4	;1
17	CIho	2242	Purple Nepal	USA	7	2	111	0	I	4	;1
18	CIho	2260	Mochi Hadaka	Japan	6	2	108	1	MSI	4	4
19	CIho	2261	Pusa	USA	5	2	102	2	MRR	3C	4
20	CIho	2318	Kharsila	India	1	3	100	2	MRR	4	4

[1]Acession number assigned by USDA-ARS Aberdeen, ID
[2]Name of cultivar from country of origin
[3]Cultivar country of origin
[4]Color of seed on a scale of 1 to 10, 1=very light brown, 2=light brown, 3=light/dark brown, 4=brown blue, 5=blue, 6=blue/brown/purple, 7=brown/purple, 8=dark purple
[5]1 to 3=starchy, 4 and 5=waxy
[6]Julian heading date-days from 1 January
[7]Awn type, 0=awnless, 1=short awned, 2=long awned, H=hooded
[8]Powdery mildew reaction, R=resistant, MR=moderately resistant, I=intermediate, MS=moderately susceptible, S=susceptible, C=chlorotic reaction, N=necrotic reaction
[9]Infection type, 0-1=resistant, 2=moderately resistant, 3=moderately susceptible, 4=susceptible, + =increased susceptibility, - =decreased suscepibility, ; =necrotic flecking resistance reaction, C=chlorotic reaction, N=necrotic reaction

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
21	CIho	2320	Black Hulless	China	1	3	102	2	MRR	4	0;
22	CIho	2423	Mochi Hadaka	Japan	6	2	106	2	MSI	23C	234
23	CIho	2426	Nangmay	China	1	3	102	2	I	4	4
24	CIho	2428	Poree	Korea	1	3	106	2	MS	4	4
25	CIho	2429	Mavnang	China	4	3	107	2	I	4	4
26	CIho	2457	Lokian	China	3	2	98	2	MSI	4	12
27	CIho	2458	Watho	China	4	3	101	2	I	23C	234
28	CIho	2465	Orkoe	China	1	3	100	2	I	4	4
29	PI	57024	FLE No. B519	Nepal	4	3	111	2	MS	3C	4
30	PI	57948	Gujar Khan	Pakistan	5	2	100	2	MR	23C	4
31	PI	57964	Black B.S.	Pakistan	8	2	101	2	MRR	3C	0;N
32	PI	64524	Ciho 4218	India	1	3	99	2	S	4	;1=
33	PI	69131	Nahaver	China	7	3	117	2	0MS	3C	NA
34	PI	82681	5085	China	3	3	110	2	MS	4	4
35	PI	82682	5086	China	1	3	100	0	MSI	3C	4
36	PI	82687	Suchow	China	1	3	106	2	MS	3C	234
37	PI	87751	Kozan	Korea	1	2	107	1	I	4	234
38	PI	87762	Tonsaru Pori	Korea	1	3	107	2	MS	4	4
39	PI	87775	Shimabara	Korea	3	3	105	1	MR	4	4
40	PI	87778	Hadakamugi	Korea	1	3	105	2	S	4	4
41	PI	95399	Shiro Mochi	Japan	3	3	107	2	MSS	4	4
42	PI	95398	Murasaki Mochi	Japan	7	4	107	2	MRI	23C	4
43	PI	97331	Stadler	Japan	7	4	107	2	MR	3C	4
44	PI	97330	Stadler	Japan	6	4	107	2	MR	3C	4
45	PI	97332	Stadler	Japan	3	3	106	2	MS	4	4
46	CIho	5929		China	3	3	100	2	I	4	4
47	CIho	5931		China	1	3	105	2	I	4	4
48	CIho	5932		China	7	3	102	2	MRI	4	4
49	CIho	5934		China	1	3	106	2	MS	4	4
50	CIho	5935		China	1	3	105	2	MSI	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
51	CIho	5936		China	1	2	105	2	MSI	4	4
52	CIho	5937		China	1	3	102	2	I	4	234
53	CIho	5938		China	3	3	106	2	MRI	4	4
54	CIho	6041	Kobai	Japan	3	3	101	1	I	4	4
55	CIho	6045	Shinkiki	USA	3	3	107	1	MSI	23C	234
56	CIho	6057		USA	4	3	109	2	MS	4	4
57	CIho	6062	High Fertility Naked UM	USA	4	3	115	2	S	4	4
58	PI	116514	Manga jau	India	4	3	103	1	R	4	4
59	CIho	6185	Deciduoslem	China	1	3	102	2	MSI	4	4
60	PI	122018	Salzot	India	4	3	98	2	I	3N	4
61	PI	122019	Sermo Ringruo	India	5	2	114	2	MS	4	4
62	PI	128518	Ciho 6345	India	3	3	102	2	I	4	4
63	CIho	6365	Disentis Kloster	Switzerland	3	3	108	2	MSI	4	234
64	PI	129506	Ciho 6474	Poland	7	2	116	0	S	4	4
65	CIho	6479		China	1	3	107	0	MS	3N	4
66	PI	134632	Ciho 6587	Afghanistan	3	3	109	2	MSI	4	4
67	CIho	6601		Afghanistan	4	3	109	2	MS	4	4
68	CIho	6602		Afghanistan	3	3	107	2	MSI	4	4
69	CIho	6603		Afghanistan	4	3	108	2	MS	4	4
70	CIho	6706		India	3	3	109	2	MR	4	4
71	CIho	6727	Curly	USA	4	2	102	2	S	4	4
72	CIho	6838	Marys Pride and Joy	USA	3	2	107	2	MS	4	23
73	PI	155089	Aizu No. 3	Japan	1	3	96	2	I	4	234
74	PI	155101	Wase Hadaka	Japan	1	3	100	1	MR	4	4
75	CIho	7332	Aizu Hadaka No. 3	Japan	1	3	106	0	I	4	23
76	CIho	7334	EhimeHadaka No. 1	Japan	3	2	104	2	MRI	4	4
77	CIho	7335	EijoHadaka	Japan	3	3	102	1	MRI	3C	234
78	CIho	7336	HadakaRikun No. 1	Japan	3	3	108	1	MRI	4	234
79	CIho	7337	Hakuto	Japan	1	3	105	1	S	4	4
80	CIho	7338	JoshuShirohadaka	Japan	3	3	102	1	I	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
81	CIho	7339	KagawaHadaka 1	Japan	3	3	103	1	MRI	3CN	4
82	CIho	7340	KairyoShirohadaka	Japan	1	3	106	1	I	4	4
83	CIho	7341	Kamaon 1	Japan	1	3	102	2	MSI	4	4
84	CIho	7343	KobaiSai	Japan	1	3	102	1	I	4	4
85	CIho	7344	Kobinkatagi	Japan	1	3	108	1	MRI	4	4
86	CIho	7345	Kobinkatagi 36	Japan	3	3	107	1	S	4	4
87	CIho	7346	KochiWasehadaka	Japan	3	3	97	2	MR	4	4
88	CIho	7347	Kasaba 2	Japan	3	3	106	2	MS	4	4
89	CIho	7348	Nejire 2	Japan	3	3	105	1	S	4	4
90	CIho	7349	OitaHadaka	Japan	1	3	107	1	I	3C	234
91	CIho	7352	Shikke Shirazu	Japan	1	3	105	1	S	4	4
92	CIho	7353	ShimabaraHadaka	Japan	1	3	107	1	MS	4	4
93	CIho	7354	ShinShinriki 1	Japan	1	3	105	1	MSI	3C	4
94	CIho	7355	Shiraumo	Japan	4	3	102	1	MS	4	4
95	CIho	7356	Shirochinko	Japan	3	3	102	1	MRI	4	4
96	CIho	7357	Shirohadaka 1	Japan	1	3	105	2	I	4	234
97	CIho	7358	Shiromugi 8	Japan	3	3	102	1	S	4	4
98	CIho	7359	Takeshita	Japan	3	3	107	1	MS	23C	4
99	CIho	7361	Wase Hadaka	Japan	3	3	96	1	MS	4	4
100	CIho	7363	Yane Hadaka 1	Japan	4	3	108	1	MSI	3C	4
101	CIho	7380	Mansiki	Japan	1	3	106	1	S	4	4
102	PI	157650	BacDong 38	Korea	1	3	107	2	MS	4	4
103	PI	157653	BaecDong	Korea	1	3	99	2	I	4	4
104	PI	157655	Buan Buisaru	Korea	1	3	107	1	MS	4	4
105	PI	157661	Cha Shu Shiro Hataka	Korea	3	3	100	1	MSI	4	4
106	PI	157662	Nagasaki Wase Hataka	Korea	3	2	94	1	I	4	234
107	PI	157663	ChangMac	Korea	1	3	105	1	S	4	234
108	PI	157667	ChinAnDong	Korea	3	2	105	2	I	4	23
109	PI	157668	ChoShinRyac	Korea	3	3	102	1	MSI	4	1=
110	PI	157675	KabinKataki 4	Korea	4	3	106	1	MRI	4	23

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
111	PI	157676	KayangChaaRae	Korea	1	3	101	1	I	4	4
112	PI	157677	KwiraChonBuc 53	Korea	1	3	105	2	I	4	4
113	PI	157679	KyonChal	Korea	1	3	105	2	I	4	4
114	PI	157683	OWi	Korea	1	3	104	1	MSI	4	4
115	PI	157684	PyangGoRa	Korea	3	3	104	1	MS	3C	;1=
116	PI	157686	SamTo	Korea	3	2	103	1	MRI	4	4
117	PI	157690	Shin No. 4	Korea	1	3	101	1	MRI	4	4
118	PI	157723	Shima Bara	Korea	3	3	103	1	MS	3C	4
119	PI	157725	YucU No. 1	Korea	3	3	109	2	MSI	4	4
120	PI	163071	Marua Jau	India	5	3	100	2	S	4	234
121	PI	163072	Marua Jau	India	4	3	99	2	S	4	4
122	PI	163075	Marau Java	India	4	3	99	2	S	4	4
123	PI	163081	Salzot	India	4	3	102	2	MS	4	4
124	PI	163082	Nanga Jau	India	4	3	99	1	R	4	4
125	PI	163596	Ware	Guatemala	1	3	107	2	S	4	23
126	PI	165877	Jisala Oowa	India	3	3	105	2	MSI	4	4
127	PI	165878	Oowa	India	4	3	104	2	MR	4	4
128	PI	165879	Oowa	India	4	3	103	1	MRI	4	4
129	PI	165889	9338a	India	1	3	101	1	MSI	4	4
130	PI	165932	Oowa	India	4	3	102	2	MRI	4	4
131	PI	165953	Oowa	India	1	3	104	2	I	4	4
132	PI	165956	Oowa	India	3	3	108	1	MRI	4	4
133	PI	165966	Patansm Sermo	India	3	2	102	0	MRI	4	4
134	PI	165969	Salzot	India	5	3	109	2	S/MR	4	234
135	PI	165973	Oowa	India	4	3	105	1	MRI	4	;1
136	PI	165976	Oowa	India	4	3	106	1	MR	4	4
137	PI	165979	Oowa	India	1	3	105	2	MSI	4	4
138	PI	165985	Oowa	India	3	3	107	1	MR	4	4
139	PI	165991	Oowa	India	4	3	105	2	I	4	234
140	PI	166024	Oowa	India	3	3	101	2	MRI	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]	Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
141	PI 166029	Oowa	India	3	3	107	2	I	4	NA
142	PI 166052	Oowa	India	3	3	103	1	RMR	4	234
143	PI 166055	Oowa	India	3	3	107	1	MR	4	4
144	PI 166056	Oowa	India	3	3	106	1	MR	4	4
145	PI 166067	Oowa	India	3	3	106	1	MR	4	4
146	PI 166076	Oowa	India	3	2	106	2	MR	4	NA
147	PI 166077	9621	India	3	3	101	1	MR	4	2
148	PI 166078	Lendow Oowa	India	3	3	103	1	MRR	4	4
149	PI 166079	9623	India	3	3	104	1	MRR	4	4
150	PI 166080	9624	India	3	3	101	1	MRR	4	4
151	PI 166088	Oowa	India	3	3	102	2	MRR	4	12
152	PI 166092	Oowa	India	1	3	104	1	MRR	4	4
153	PI 166093	Oowa	India	1	3	105	1	MRR	4	4
154	PI 166094	Oowa	India	5	3	102	1	R	4	4
155	PI 166095	Jisala Oowa	India	3	3	101	2	MRR	4	4
156	PI 166096	9641	India	3	3	100	2	MR	4	4
157	PI 166115	Oowa	India	3	3	101	2	MR	4	4
158	PI 166168	NP 24	India	5	3	99	2	S	4	4
159	PI 166185	Patani Zatt	India	7	3	108	1	MS	4	4
160	PI 166186	Sermo	India	3	3	108	1	MRI	4	4
161	PI 166191	9737	India	3	3	102	1	MR	4	12
162	CIho 7789	Sagatairyu	Japan	3	3	105	2	MSI	4	4
163	CIho 8081	8444	India	7	3	99	2	I	4	4
164	CIho 8083	9633	India	4	3	101	120	MRI	4	4
165	CIho 8084	9641	India	3	3	104	1	MRR	4	4
166	PI 176003	Jao	India	4	3	100	2	MR	4	12
167	PI 176004	Oowa	India	4	3	101	2	I	4	4
168	PI 176005	Oowa	India	3	3	102	2	MR	4	4
169	PI 176006	Oowa	India	3	3	102	1	MR	4	4
170	PI 176009	Jao	India	3	3	104	2	I	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
171	PI	176013	9408a	India	3	3	106	2	I	4	234
172	PI	176020	Oowa	India	4	3	107	1	MRR	4	4
173	PI	176023	Oowa	India	4	3	109	1	MR	4	4
174	PI	176026	Oowa	India	3	3	107	2	MRR	4	4
175	PI	176029	Oowa	India	5	3	107	1	MR	4	4
176	PI	176033	Oowa Jao	India	3	3	106	2	MR	4	4
177	PI	176034	Oowa Jao	India	3	2	106	2	MRR	4	4
178	PI	176036	Oowa	India	3	3	100	1	MRR	4	4
179	PI	176038	Oowa	India	4	2	101	1	MR	4	4
180	PI	176039	Chema	India	4	3	102	2	I	3N	4
181	PI	176041	Chema	India	4	2	105	1	MRI	4	4
182	PI	176043	Tsema	India	4	2	104	2	MS	3C	4
183	PI	176048	9524b	China	4	2	106	2	MS	4	4
184	PI	176049	9526a	Nepal	4	3	107	2	MRI	4	4
185	PI	176050	Tsema	India	4	3	107	2	I	23N	4
186	PI	176052	Tsema	India	4	3	99	1	MRR	4	4
187	PI	176056	Tsema	India	4	3	100	1	MR	4	4
188	PI	176059	Tsema	India	4	3	104	2	MRR	4	4
189	PI	176063	Oowa	India	1	3	92	1	MS	4	4
190	PI	176071	Oowa	Nepal	5	2	105	1	I	3C	4
191	PI	176077	Tsema	India	5	3	106	1	MSI	4	4
192	PI	176080	Oowa	India	4	3	107	1	MRR	4	4
193	PI	176081	Seetua	India	4	3	102	2	MRI	4	4
194	PI	176085	Oowa	India	4	3	100	1	I	4	4
195	PI	176086	Tsema	India	3	3	99	1	MRR	3N	4
196	PI	176089	Tsema	India	4	3	107	1	MR	4	4
197	PI	176090	Tingtsema	India	4	3	109	1	MRI	4	4
198	PI	176091	Shi Tsema	India	5	3	105	1	MRR	4	4
199	PI	176094	9662a	Nepal	4	3	100	1	MR	4	4
200	PI	176096	Pangu	India	3	3	101	2	MRI	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
201	PI	176099	Oowa	India	3	3	102	1	I	4	4
202	PI	176102	Oowa	India	3	3	100	1	MSI	4	4
203	PI	176104	Oowa	India	3	3	102	2	MRR	4	4
204	PI	176111	Oowajao	India	4	3	102	2	MRI	4	4
205	PI	176113	Oowajao	India	3	3	99	2	S	4	4
206	PI	176115	Oowajao	India	3	3	101	1	MR	4	4
207	PI	176118	Oowajao	India	3	3	102	2	MRR	4	4
208	PI	176119	Oowajao	India	1	3	102	1	MR	4	4
209	PI	176122	Oowajao	India	3	3	99	2	MS	4	4
210	PI	176124	Oowajao	India	3	3	99	2	S	4	4
211	PI	176126	Oowa	India	3	3	100	2	MS	4	4
212	PI	176135	Oowajao	India	3	3	99	2	MS	4	4
213	PI	176136	Oowajao	India	3	3	100	2	MR	4	4
214	PI	176139	Oowajao	India	3	3	101	2	MRR	4	4
215	PI	176140	Oowajao	India	3	3	100	2	MS	4	4
216	PI	176143	Oowajao	India	3	3	100	2	MS	4	4
217	PI	176147	Oowajao	India	3	3	100	2	MR	4	4
218	PI	176150	Oowajao	India	3	3	101	2	MSI	4	4
219	PI	176152	Oowajao	India	3	3	100	2	MS	4	4
220	PI	176154	Oowajao	India	1	3	100	2	R	4	4
221	PI	176167	Oowajao	India	3	3	101	2	MRR	3N	4
222	PI	180645	Bethge Nacht	Germany	4	3	109	20	MS	4	4
223	PI	181090	Oowajao	India	3	3	100	2	MSI	4	4
224	PI	181091	Oowajao	India	1	3	101	2	R	4	4
225	PI	181094	Salzot	India	5	3	114	2	MS	4	4
226	PI	181096	Pangizat	India	3	3	106	0	MR	4	4
227	PI	181097	Srmo	India	1	3	110	2	MRR	4	4
228	PI	181098	Salzot	India	5	3	114	2	MS	4	4
229	PI	181099	Zat	India	4	3	114	2	MSI	3C	4
230	PI	181100	Bhatne	India	4	3	114	2	MSI	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
231	PI	181102	10596	India	5	3	113	2	MSI	4	4
232	PI	182506	Markhinetz	USA	1	3	108	2	MRI	4	4
233	PI	182603	Kairyo Hadaka	Japan	3	3	102	1	MR	3C	4
234	PI	182604	Kairyo Bozu	Japan	3	3	101	1	MR	4	4
235	PI	182605	Sangatsu Hadak No. 1	Japan	3	3	94	2	I	4	4
236	PI	182610	Aizu Hadaka	Japan	1	2	112	1	S	4	4
237	PI	182611	Osaka No. 6	Japan	3	3	111	1	S	3C	4
238	PI	182612	Kodama No. 13	Japan	1	3	101	1	MSI	4	4
239	PI	182613	Kobai No. 10	Japan	3	3	101	1	I	4	4
240	PI	182614	Kagoshima Kobai	Japan	3	3	106	1	MS	4	4
241	PI	182616	Mikuriya	Japan	3	3	102	1	MRI	4	4
242	PI	182617	Mihohadaka	Japan	3	3	105	1	MSI	4	4
243	PI	182623	Ouchi No. 1	Japan	1	3	108	1	MSI	3C	4
244	PI	182627	Wase Hadaka	Japan	3	3	95	1	MS	4	4
245	PI	182629	Ichinenmugi No. 2	Japan	3	3	105	2	S	4	4
246	PI	182630	Tokushima Kagawa No. 5	Japan	3	3	102	1	MR	4	4
247	PI	182631	Kagawa Hadaka	Japan	1	3	105	1	I	4	4
248	PI	182632	Michima Hadaka	Japan	3	3	105	1	I	4	4
249	PI	182633	Kosaba No. 2	Japan	3	3	104	2	MS	4	4
250	PI	182635	Shinriki Mugi	Japan	3	3	107	1	I	23C	4
251	PI	183370	Aizu Hadaka No. 3	Japan	3	3	108	1	MSI	4	;1N
252	PI	183507	11453	Nepal	3	3	104	1	MS	4	4
253	PI	186123	BaecDong	Korea	1	3	110	2	MS	4	4
254	PI	186128	ChaeRaeYukKac	Korea	1	3	109	2	S	4	234
255	PI	186133	KoyaneChaeRae	Korea	1	3	112	2	S	4	4
256	PI	190268	HenroHen	Japan	3	3	101	1	I	4	4
257	PI	190269	Henro 108	Japan	3	3	104	1	MS	4	4
258	PI	190270	Kairyo Bozu	Japan	1	3	104	1		4	4
259	PI	190273	Oshichi	Japan	7	3	102	2	MS	4	4
260	PI	190277	Yanehadaka No. 2	Japan	7	3	108	1	MSI	3C	234

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
261	PI	190645	No. 3	China	6	3	115	2	S	4	4
262	PI	190661	Chan Tung	China	7	3	116	2	MS	4	4
263	PI	190678	Mu Shih Chiang 2	China	1	3	102	2	I	4	4
264	PI	190681	Ti T'ien Ch'ioa	China	1	3	105	2	I	3C	4
265	PI	190683	Ta Yeh 1	China	3	3	100	2	MS	4	234
266	PI	190694	Chiao Chuang 2	China	6	3	106	2	MSI	3C	4
267	PI	190706	Shanghai 1	China	1	4	102	2	MS	4	4
268	PI	190712	Mitsukiko No. 1	Japan	1	34	99	2	MSI	4	4
269	PI	190713	Marumi No. 16	Japan	3	3	105	2	MS	4	4
270	PI	190742	Yane No. 44	Japan	3	3	106	1	MSI	3C	4
271	PI	190750	Kokubi 1	Japan	1	2	104	2	I	4	4
272	PI	190752	Yakko No. 52	Japan	7	3	107	2	S	4	4
273	PI	190753	Akashinriki	Japan	3	3	104	1	MS	4	4
274	PI	190754	Kadama No. 13	Japan	3	3	100	1	I	4	4
275	PI	190757	Kobinkatagi No. 4	Japan	4	3	104	1	MS	4	234
276	PI	190760	Kobinkatagi	Japan	3	2	107	1	S	4	4
277	PI	190762	Kobai No. 10	Japan	1	3	102	1	I	4	4
278	PI	190764	J57	Japan	3	3	101	1	MS	4	4
279	PI	190765	Yanehadaka No. 2	Japan	4	3	100	1	I	23C	4
280	PI	190766	Kairyo Bozu Mugi	Japan	1	3	104	1	I	4	234
281	PI	190770	KochiWasehadaka	Japan	3	3	93	2	MRI	4	234
282	PI	190771	Takeshita	Japan	1	3	109	1	I	23C	234
283	PI	190773	Shimabara	Japan	3	3	106	1	MS	4	4
284	PI	190774	OitaNejire	Japan	3	3	108	1	S	4	4
285	PI	190775	Kosaba 1	Japan	3	4	108	2	MS	4	4
286	PI	190777	Kamaore No. 1	Japan	3	3	104	2	I	4	4
287	PI	190782	Komehadaka	Japan	1	3	102	2	MS	4	4
288	PI	190784	Bozu	Japan	3	4	105	12	MSI	4	4
289	PI	190785	Awamugi	Japan	7	3	107	1	I	4	4
290	PI	190813	Uessarupori	Korea	1	3	112	2	MSI	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]	Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
291	PI 190814	Kojo Zairai	Korea	6	3	109	2	MS	4	23
292	PI 190819	Kojo Zairai	Korea	1	3	113	2	MS	4	4
293	PI 190841	Chosindo Hadaka	Korea	1	3	110	2	MS	4	4
294	PI 190846	Fuanwaisarupori	Korea	1	3	107	1	S	4	4
295	PI 190847	Aomugi	Korea	3	3	105	1	MSS	4	4
296	PI 190848	Ningutsudo Hadaka	Korea	1	3	109	2	S	4	4
297	PI 190849	Chin'an Dohadaka	Korea	1	3	108	2	MSI	4	4
298	PI 190851	Kokujo	Korea	1	3	109	2	I	4	4
299	PI 190852	Kozan	Korea	4	3	107	1	S	4	4
300	PI 190853	Kakkyo	Korea	1	3	108	1	S	4	4
301	PI 194549	Chinko	Germany	7	3	109	1	S	4	4
302	PI 194555	Stamm JH 538946	Germany	3	3	109	2	R	3C	234
303	PI 195542	Tibetan	China	4	2	95	1	MS	4	4
304	PI 202898	962	China	3	3	107	1	MRR	4	4
305	PI 202900	971	China	6	3	116	2	I	3C	4
306	PI 202901	973	China	7	3	109	2	S	4	NA
307	PI 202903	983	China	4	3	102	2	MSI	4	234
308	PI 202904	986	China	4	3	102	2	MS	4	4
309	PI 202905	989	China	4	3	102	2	S	4	4
310	PI 202910	1001	China	7	3	100	2	S	4	4
311	PI 202911	1003	China	8	2	102	2	MS	4	234
312	PI 202912	1005	China	8	2	100	2	S	4	4
313	PI 202913	1016	China	3	2	101	2	S	4	4
314	PI 202914	1022	China	7	2	109	2	I	4	4
315	PI 202919	1035	China	6	2	108	2	MR	4	4
316	PI 202921	1041	China	6	1	112	2	S		NA
317	PI 202928	1083	China	1	1	109	1	I	4	4
318	CIho 9940		China	6	1	99	2	MS	4	4
319	PI 225128	Ciho 9985	Iran	4	1	105	2	MSI	4	4
320	PI 217534	13936	Pakistan	8	3	102	2	R	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
321	PI	225016	ChoshiroHen	Japan	3	2	112	1	MS	4	4
322	PI	225017	Ehimehadaka No. 1	Japan	3	2	106	1	I	3C	4
323	PI	225018	HenroHen	Japan	3	2	104	1	MRI	4	4
324	PI	225024	Yane Hadaka Hen	Japan	3	3	109	1	MRI	4	234
325	PI	225025	Yane Hadaka No. 2	Japan	3	3	109	1	MRI	3C	4
326	CIho	10547		China	4	1	93	2	S	4	4
327	PI	242106	Isehadaka	Japan	3	1	107	1	MR	4	4
328	CIho	10625	Hakuto	Japan	3	1	106	1	S	4	4
329	CIho	10626	Kogawa Hadaka 1	Japan	3	2	107	1	MR	3C	4
330	CIho	10627	Kobinkatagi 36	Japan	3	1	107	1	S	4	4
331	CIho	10628	Kasaba 2	Japan	1	1	107	2	S	4	4
332	CIho	10629	Bozu Omugi	Japan	3	2	105	2	S	4	4
333	CIho	10630	Kasaba	Japan	3	2	111	1	MSI	4	4
334	CIho	10632	Mejire No. 2	Japan	3	2	106	1	I	4	4
335	CIho	10634	Shimabara Hadaka	Japan	1	3	109	1	MS	4	4
336	CIho	10636	Utah B855142	USA	3	2	117	2	MR	23C	4
337	PI	251269	K377	Pakistan	7	2	107	1	MR	4	4
338	CIho	10842		Ethiopia	1	2	108	1	MRI	3C	4
339	CIho	10843		Ethiopia	3	2	108	1	I	4	4
340	CIho	10957	Komairazu	Japan	1	2	106	1	I	4	4
341	PI	270604	6	Peru	4	2	107	2	I	3N	4
342	PI	270606	8	Peru	4	2	107	2	I	4	4
343	PI	270608	10	Peru	7	2	90	2	MSI	3C	;1N
344	PI	270631	33	Peru	4	2	109	2	MS	4	4
345	PI	270665	67	Peru	1	2	118	2	I	3C	;1N
346	PI	270666	68	Peru	6	1	116	2	MS	4	;12N
347	PI	270667	69	Peru	3	1	119	2	MS	4	;12N
348	PI	270668	70	Peru	3	1	112	2	MR	3C	234
349	PI	270671	73	Peru	4	2	109	2	MSI	4	4
350	PI	270672	74	Peru	4	1	106	0	MR	3N	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
351	PI	270673	75	Peru	3	1	109	2	MR	4	23
352	PI	270687	89	Peru	4	1	118	2	I	4	;12N
353	PI	270711	113	Peru	6	1	115	2	MSI	4	4
354	PI	270715	117	Peru	4	1	107	2	MS	4	4
355	PI	270717	119	Peru	4	2	116	2	MSI	3C	;1N
356	PI	270725	127	Peru	1	1	107	2	I	4	4
357	PI	270728	130	Peru	6	1	114	0	I	4	4
358	PI	270729	131	Peru	6	1	110	2	I	4	4
359	PI	270730	132	Peru	4	1	111	2	I	3C	4
360	PI	270738	140	Peru	4	1	90	2	S	4	;1N
361	PI	270739	141	Peru	3	1	115	2	MR	4	23
362	PI	270740	142	Peru	4	1	115	2	MSI	4	;2N
363	PI	270741	143	Peru	3	1	110	2	MR	4	234
364	PI	270742	144	Peru	4	1	107	0	MRR	4	4
365	PI	270747	149	Peru	7	1	114	0	I	4	4
366	PI	270752	154	Peru	1	1	112	2	MRR	3C	4
367	PI	267719	Ciho 11326	Peru	3	1	108	2	MRR	4	234
368	CIho	11370	SC 603239	USA	4	1	110	2	MS	4	4
369	PI	269904	697	Pakistan	4	1	105	2	MRI	4	4
370	CIho	11555	A 222	Japan	3	2	105	2	I	4	4
371	CIho	11575	Ianthinum 3647	Germany	8	1	100	2	MRR	4	4
372	PI	268183	Weihenstephaner	Germany	1	2	107	2	MR	4	4
373	CIho	11757	Haramachi	Japan	4	2	112	1	MSI	4	4
374	CIho	11825	Lyallpur 3647	Pakistan	8	2	99	2	MRR	4	4
375	CIho	11836	Lyallpur 3647	Pakistan	3	3	106	H	MRR	3C	4
376	PI	283410	C.P.I. 22817	Sov Union	1	1	109	2	MS	4	4
377	PI	285624	Mlochowski Nagi	Poland	1	1	102	2	MS	4	4
378	PI	271250	CN 294	India	3	1	100	1	I	4	4
379	PI	290295	Moschimugi II	Hungary	1	1	99	2	MSI	4	4
380	PI	290311	Marumi	Hungary	3	2	107	2	I	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
381	PI	290318	Moschimugi II	Hungary	1	1	102	2	I	4	4
382	PI	290348	Razza	Hungary	3	1	114	2	S	3C	4
383	PI	294726	Jane Hadaka	Bulgaria	3	1	105	1	I	4	4
384	PI	294727	Hiza Hacha	Bulgaria	3	2	107	1	MSI	4	4
385	PI	294729	Chiro Chinko	Bulgaria	4	2	100	1	MRI	3N	4
386	PI	307494	Akashinriki	Japan	3	2	107	1	I	3C	4
387	PI	315861	trifurcatum	UK	1	2	106	H	MR	4	4
388	CIho	13347		Hungary	1	2	105	2	I	4	234
389	PI	306468	2723	Romania	3	1	107	2	MSI	4	4
390	PI	306472	2727	Romania	3	2	105	2	MR	4	234
391	PI	306473	2728	Romania	3	1	110	2	I	4	4
392	CIho	13655	Purple Nudum B24	Australia	8	2	105	2	MRR	4	4
393	PI	330505	121	UK	8	2	100	2	MRR	4	4
394	CIho	14349	Ciho 43431	China	4	2	95	2	R	4	4
395	CIho	14352	Ciho 43462	China	7	2	109	2	I	4	234
396	CIho	14353	Ciho 43463	China	3	1	109	1	MSI	4	4
397	CIho	14356	Ciho 43471	China	3	1	108	H	I	4	4
398	CIho	14358	Ciho 43473	China	4	1	90	1	I	4	4
399	CIho	14404	Ciho 59422	China	3	1	105	H1	MS	4	4
400	CIho	14795	Funny Joints	USA	4	2	108	H	MSI	4	4
401	CIho	14797	Funny Joints	USA	3	1	107	H	MS	4	4
402	CIho	14821	Freak	USA	1	1	107	H	MSS	4	4
403	CIho	15416	Belts 651918	USA	3	1	109	2	S	4	4
404	CIho	15417	Belts 66610	USA	3	1	109	2	MS	4	4
405	CIho	15420	Belts 651607	USA	4	1	90	2	MS	4	;2
406	CIho	15421	Belts 661397	USA	4	1	90	2	MS	4	4
407	CIho	15422	Belts 651823	USA	4	1	116	2	MS	4	4
408	CIho	15426	Belts 661478	USA	3	1	115	2	MRR	4	4
409	CIho	15428	Belts 68755	USA	3	1	119	2	MSI	4	4
410	CIho	15429	Belts 69933	USA	1	1	117	2	MSI	4	23

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
411	CIho	15430	Belts 671448	USA	3	1	113	2	MSI	4	4
412	CIho	15438	Belts 651613	USA	4	1	116	1	I	4	4
413	CIho	15775	77CG 181	USA	4	1	105	2	MSI	4	4
414	CIho	16054	Isogenic: Curly Awn	USA	4	1	101	H2	S	4	4
415	CIho	16258	Isogenic: 131n8	USA	3	1	90	2	MR	4	234
416	CIho	16264	Isogenic: 134n8	USA	1	2	110	2	MRR	3CN	4
417	CIho	16276	Isogenic: 140n8	USA	4	2	90	2	S	4	4
418	CIho	16278	Isogenic: 141n8	USA	4	2	119	2	S	4	4
419	CIho	16280	Isogenic: 142n8	USA	4	2	116	2	MS	4	4
420	CIho	16282	Isogenic: 143n8	USA	1	1	117	2	MS	4	4
421	CIho	16284	Isogenic: 144n8	USA	4	2	111	2	MS	4	4
422	CIho	16286	Isogenic: 145n8	USA	4	2	107	2	MS	4	4
423	CIho	16288	Isogenic: 146n	USA	3	2	119	0	MS		234
424	CIho	16290	Isogenic: 147n	USA	3	2	118	0	MS	4	234
425	PI	327976	Hor 133	Greece	6	3	106	2	MSI	23	4
426	PI	327988	Shiro Chinko	Japan	4	2	101	1	MRI	3C	4
427	PI	327991	Wase Hadaka	Japan	3	3	105	1	MSI	4	4
428	PI	327993	Shimabara	Japan	3	3	102	1	MS	4	4
429	PI	327996	Mochimugi I	Japan	3	3	105	2	MSI	4	4
430	PI	328023	Hor 202	Sov Union	3	3	102	2	I	4	4
431	PI	328046	Hor 232	China	4	3	105	2	I	4	4
432	PI	328048	Hor 234	China	3	3	105	2	I	4	4
433	PI	328624	Hor 1367	Japan	3	3	104	1	MR	4	4
434	PI	328625	Hor 1368	Sov Union	3	4	105	1	MS	4	234
435	PI	328627	Hor 1372	Japan	1	3	107	1	MRI	3N	4
436	PI	328629	Hor 1374	Germany	3	3	102	2	I	4	4
437	PI	328705	Hor 1524	China	6	3	108	2	I	3C	4
438	PI	328858	Hor 2246	Germany	1	3	114	2	MSI	4	4
439	PI	328861	Weizengerste	Germany	3	3	107	2	MRI	4	234
440	PI	328870	Milechowski	Poland	1	3	103	2	I	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
441	PI	328944	Hor 2484	China	6	2	109	2	I	4	4
442	PI	328957	EhimeHadaka 2	Japan	1	2	102	1	MS	4	234
443	PI	328959	Hor 2503	China	4	2	95	2	I	4	4
444	PI	328974	S 127	Ethiopia	8	3	107	2	I	4	4
445	PI	329007	S 3206	Ethiopia	4	3	108	2	I	4	4
446	PI	329124	Hor 2313	Hungary	3	2	102	1	I	4	4
447	PI	356158	E 364/2	Ethiopia	4	2	108	2	MRI	4	4
448	PI	356161	E 364/5	Ethiopia	4	3	107	2	MRI	4	4
449	PI	358597	22850	Ethiopia	4	3	105	2	MRR	4	4
450	PI	358599	22852	Ethiopia	1	2	104	2		4	4
451	PI	361676	6 Radet Nogen	Denmark	1	3	107	2	I	4	4
452	PI	361694	Nackte Kleine	Denmark	4	3	107	2	I	4	4
453	PI	361704	Weizen Oder Edel	Denmark	4	3	109	2	I	4	4
454	PI	361709	Inka	Denmark	1	3	107	2	I	4	4
455	PI	370767	27A	Switzerland	3	3	107	2	I	4	4
456	PI	370793	155A	Switzerland	1	3	107	2	I	12	4
457	PI	370799	179A	Switzerland	3	2	115	2	MSI	23	4
458	PI	370802	199A	Switzerland	3	3	114	2	MRR	12	4
459	PI	370835	238M	Germany	3	2	108	2	I	23	4
460	PI	370851	272B	Switzerland	3	3	107	2	MSI	23	4
461	PI	371335	1970BA	Switzerland	4	2	111	2	I	23	4
462	PI	371346	1972A	Switzerland	4	2	108	2	I	23	4
463	PI	371400	2028A	Switzerland	4	3	108	2	MSI	4	4
464	PI	388746	Line 140	China	3	2	106	1	I	4	4
465	PI	388747	NanFan 3	China	3	2	108	2	MSI	4	4
466	PI	428368	Yuan Meh 757	China	3	2	95	1	MS	4	4
467	PI	429506	NB12A	Nepal	4	2	100	H1	MS	3C	4
468	PI	429508	NB15A	Nepal	4	2	100	H1	MSI	23C	4
469	PI	429513	NB19A	Nepal	4	3	100	H1	MS	3C	4
470	PI	429517	NB22A	Nepal	4	2	100	H1	MS	3C	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]	Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
471	PI 429520	NB25A	Nepal	3	3	100	H1	MS	4	4
472	PI 429549	NB54B	Nepal	3	3	102	1	S	4	4
473	PI 429560	NB61A	Nepal	3	3	102	2	I	12	4
474	PI 429563	NB63B	Nepal	3	3	102	H1	MR	23	4
475	PI 429570	NB68A	Nepal	4	2	102	2	S	4	4
476	PI 429573	NB72B	Nepal	3	3	102	2	MS	4	4
477	PI 429575	NB74A	Nepal	6	2	98	2	S	4	4
478	PI 429579	NB78A	Nepal	3	3	102	1	MRI	4	4
479	PI 429581	NB81A	Nepal	3	3	104	1	I	4	4
480	PI 429582	NB82A	Nepal	4	3	105	H1	I	4	4
481	PI 429584	NB83A	Nepal	3	2	103	1	MRI	4	4
482	PI 429586	NB84A	Nepal	4	2	102	1	MS	4	4
483	PI 429588	NB86A	Nepal	4	2	100	2	MS	23C	4
484	PI 429589	NB87A	Nepal	4	2	102	2	MS	23C	4
485	PI 429591	NB88A	Nepal	4	2	101	2	MS	3C	4
486	PI 429592	NB88B	Nepal	4	3	99	2	MS	23C	4
487	PI 429593	NB89A	Nepal	4	3	99	2	MSI	3C	4
488	PI 429943	N191	India	4	3	109	2	MS	3C	4
489	PI 429944	N192	India	4	3	109	2	IMS	23C	4
490	PI 429956	N211	India	3	3	99	2	S	4	4
491	PI 429964	N221	India	3	3	99	2	MS	4	4
492	PI 429977	N234	India	4	3	107	2	MS	23	4
493	PI 429981	N237	India	4	3	102	2	MR	4	4
494	PI 429990	N245	India	3	2	101	2	I	4	4
495	PI 447304	ST59	China	3	3	113	2	MRI	4	4
496	PI 447327	ST97	China	6	3	97	2	MS	4	4
497	PI 447336	Che No. 114 Yan Mai	China	3	3	102	1	MSI	23	4
498	PI 477776	UNA 8302	Peru	3	3	107	2	MR	4	4
499	PI 477789	UNA 8317	Peru	1	3	106	H1	MS	4	4
500	PI 477798	UNA 8327	Peru	4	3	109	2	MS	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]	Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
501	PI 477804	UNA 8334	Peru	4	2	108	2	MS	4	4
502	PI 477805	UNA 8336	Peru	4	3	107	2	MS	4	4
503	PI 477808	UNA 8339	Peru	3	3	106	2	MS	4	4
504	PI 477810	UNA 8341	Peru	3	2	108	2	S	4	4
505	PI 477813	UNA 8346	Peru	4	2	108	2	MS	4	4
506	PI 477819	UNA 8355	Peru	3	3	107	2	MS	4	4
507	PI 477820	UNA 8356	Peru	3	3	107	2	MS	4	4
508	PI 477822	UNA 8358	Peru	4	3	108	2	MSI	4	4
509	PI 477823	UNA 8359	Peru	3	3	107	2	MSI	4	4
510	PI 477826	UNA 8362	Peru	3	3	102	2	MRI	3C	4
511	PI 477832	UNA 8368	Peru	3	2	107	2	MS	4	234
512	PI 477836	UNA 8372	Peru	4	3	106	2	MRI	23C	4
513	PI 477838	UNA 8375	Peru	3	3	101	2	I	3C	4
514	PI 477850	UNA 8387	Peru	4	3	91	2	S	4	4
515	PI 477861	UNA 8461	Peru	3	2	107	2	MRR	4	4
516	PI 565538	Hu Lu Tou2	China	3	3	101	H1	MS	4	4
517	PI 565542	Yang Yung Mi Da Mai	China	4	3	108	2	MSI	4	4
518	PI 565543	Wan Xian Mi Da Mai	China	7	2	105	2	MSI	4	4
519	PI 565544	Zhuo Xian Luo Mai	China	7	2	102	2	MS	4	4
520	PI 565545	Long Yao Mi Da Mai	China	1	3	109	2	I	4	4
521	PI 565631	Chun Gong Zi	China	7	2	105	2	MS	4	4
522	PI 565633	Bai Gong Da Mai	China	4	3	109	2	MSI	4	4
523	PI 565641	Mi Mai	China	3	3	106	H	MSI	4	4
524	PI 565642	Gong Da Tou	China	4	3	105	2	MR	3N	4
525	PI 565643	Liu Leng Zi Gong Da Mai	China	3	2	108	2	MS	3N	4
526	PI 565644	Nu Da Mai	China	3	2	99	H	MR	4	4
527	PI 565645	Ben Da Mai	China	3	2	108	2	I	23	4
528	PI 565646	Gong Da Mai	China	3	3	109	2	MRI	23	4
529	PI 565647	Bai Gong Zi Da Mai	China	3	2	109	2	I	23	4
530	PI 565648	Hui Gong Da Mai	China	4	3	103	2	I	23	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
531	PI	565649	Hui Gong Da Mai	China	4	3	102	2	MRI	2	4
532	PI	565651	Chang Mang Da Mai	China	1	3	107	2	MRI	23	4
533	PI	565652	Luo Da Mai	China	3	3	112	2	I	4	4
534	PI	565654	Tuo Pi Da Mai	China	3	3	102	2	I	4	4
535	PI	565655	Mi Da Mai	China	3	3	112	2	I	3C	4
536	PI	565656	San Yue Huang	China	3	3	109	H	I	4	4
537	PI	565657	Mi Da Mai	China	3	3	109	2	I	4	4
538	PI	565658	Mi Da Mai	China	3	3	109	2	I	4	4
539	PI	565659	Mi Da Mai	China	3	3	108	2	MS	4	4
540	PI	565660	Bai Mi Da Mai	China	3	3	109	2	MRI	3C	4
541	PI	565661	San Yue Huang	China	3	3	109	2	MS	4	4
542	PI	565669	Lu Ren Da Mai	China	3	3	100	2	I	4	4
543	PI	565670	Qing Lu Ren	China	3	3	107	2	MSI	4	4
544	PI	565671	Lu Ren Da Mai	China	3	3	109	2	I	4	4
545	PI	565672	Lu Ren	China	4	3	109	2	I	4	4
546	PI	565674	Lu Ren Da Mai	China	4	3	99	H	MRI	4	4
547	PI	565675	Mi Da Mai	China	4	3	108	2	MS	4	4
548	PI	565676	Lu Ren Da Mai	China	3	3	107	2	MS	4	4
549	PI	565677	Lu Ren Da Mai	China	3	4	107	2	MSI	4	4
550	PI	565678	Huo Deng Mang	China	3	3	108	2	MSI	4	4
551	PI	565679	Tu Lu Ren	China	3	2	107	1	MS	4	4
552	PI	565680	Niu Xin Shao Da Mai	China	3	2	108	2	MS	4	4
553	PI	565681	Mi Da Mai	China	3	2	111	2	MSI	4	4
554	PI	565682	Nu Da Mai	China	3	3	107	1	MSI	4	4
555	PI	565683	Luo Da Mai	China	3	3	102	2	I	4	4
556	PI	565694	Da Mai	China	3	3	101	2	I	4	4
557	PI	565704	Da Mai	China	4	2	113	2	MR	4	4
558	PI	565710	Mi Da Mai	China	3	2	112	2	R	4	4
559	PI	565711	Huo Shao Tou Lu Ren	China	3	2	102	H	I	4	4
560	PI	565712	Jiu Lu Ren	China	3	3	102	2	I	4	234

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
561	PI	565713	Duan Mang Qing Ke	China	1	3	107	H1	MRI	4	4
562	PI	565714	Guang Nao	China	7	3	100	0	MRI	4	4
563	PI	565715	Qing Ke	China	3	2	99	2	I	4	4
564	PI	565716	Chang Mang Liu Leng	China	3	3	100	2	I	4	4
565	PI	565813	Pang Na	China	3	2	105	2	I	3C	4
566	PI	565868	Yu Zhong Qing Ke	China	4	3	100	2	I	4	4
567	PI	565936	116883	China	3	2	98	2	I	4	4
568	PI	565937	116885	China	3	3	102	2	I	4	4
569	PI	565938	Zao Shu 41	China	3	3	108	1	I	4	4
570	PI	565939	Yuan Mai 114	China	3	3	105	1	MSI	4	23
571	PI	565940	116897	China	3	3	99	1	MS	23C	4
572	PI	565941	Hei Liu Zhu Yan Mai	China	3	3	101	2	I	3C	4
573	PI	565943	Ching Ming Hei Liu Zhu	China	3	3	105	2	I	3C	4
574	PI	565944	Bai Liu Zhu Yan Mai	China	3	3	102	2	I	3C	4
575	PI	565945	Liu Zhu Tou	China	4	3	103	2	MSI	4	4
576	PI	565946	Hong Jin Liu Zhu Tou	China	3	3	102	2	MS	3C	4
577	PI	565947	Hong Jing Liu Zhu Tou	China	3	3	107	2	I	3C	4
578	PI	565952	Gao Jiao Er Leng Luo Mai	China	1	3	111	2	I	4	4
579	PI	565953	Xin Deng Mi Da Mai	China	3	3	102	2	I	4	4
580	PI	565955	Yu Yao Nuo Mai	China	3	3	100	2	I	4	4
581	PI	565956	Dai Shan Lao Tuo Xu	China	3	2	105	2	I	4	4
582	PI	565958	Dong Yang Hu Da Mai	China	3	2	101	2	I	4	4
583	PI	565959	Pan An Nuo Mai	China	3	3	100	2	I	4	4
584	PI	565960	Long You Mi Mai	China	3	2	105	2	I	4	4
585	PI	565961	Chang Shan Ni Qiu Mai	China	3	3	102	2	I	4	4
586	PI	565963	Kai Hua Luo Da Mai	China	3	2	102	2	I	4	4
587	PI	565964	Kai Hua Luo Da Mai	China	3	2	101	2	I	3N	4
588	PI	565965	Long Quan Si Leng	China	3	3	102	2	MS	4	4
589	PI	565966	Xiao Shan Chi Mi Mai	China	3	3	105	2	I	4	4
590	PI	565968	Chong De Si Leng Mi Mai	China	3	2	106	2	I	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
591	PI	565970	Shang Yi Liu Leng Luo Mai	China	3	2	99	2	MSI	4	4
592	PI	565972	117000	China	3	2	105	2	I	4	4
593	PI	565973	117002	China	3	3	107	2	MS	4	4
594	PI	565974	Tian Tai Luo Mai	China	3	3	105	2	I	4	4
595	PI	565975	Li Shui Wu Mang Luo Mai	China	3	3	99	H	I	4	4
596	PI	565996	Yu Da Mai	China	3	2	100	2	MRI	4	4
597	PI	565997	Yuan Mai	China	3	2	105	2	MRI	4	4
598	PI	565998	Xie Si Lun Mi Da Mai	China	4	3	102	2	MRI	4	4
599	PI	565999	Ba Gu Tao	China	3	3	101	2	MRI	4	4
600	PI	566000	Mi Mai	China	3	2	102	2	I	4	4
601	PI	566001	Zao Da Mai	China	3	2	106	2	IMS	4	4
602	PI	566003	Mi Da Mai	China	3	2	97	1	S	4	4
603	PI	566004	En Shi San Yue Huang	China	3	2	99	2	MR	4	4
604	PI	566005	Mi Mai	China	3	2	102	2	I	4	4
605	PI	566007	Mi Da Mai	China	3	2	107	2	I	4	4
606	PI	566009	Da Mi Mai	China	3	2	105	2	MS	4	4
607	PI	566014	Lao Wu Hu Xu Mai	China	3	3	104	2	S	4	4
608	PI	566015	Xu Da Mai	China	7	3	105	2	MS	4	4
609	PI	566016	Xu Da Mai	China	3	3	105	2	S	4	4
610	PI	566017	Chang Xu Da Mai	China	3	3	107	2	MS	4	4
611	PI	566021	Lao Wu Hu Xu Mai	China	7	3	107	2	R/1S	4	4
612	PI	566022	He Shang Da Mai	China	7	3	107	2	R/1S	4	4
613	PI	566032	Hong Qing Ke	China	3	2	107	2	I	4	4
614	PI	566034	Zao Bai Qing Ke	China	3	3	102	2	MS	4	4
615	PI	566038	Se Cha 2 Hao	China	4	2	112	2	MS	4	4
616	PI	566050	Liu Leng Bai Qing Ke	China	3	3	105	2	I	23	4
617	PI	566051	Zhen Tou Mai 1 Hao	China	3	2	102	2	MRI	23	4
618	PI	566056	Mu Shu Hei Qing Ke	China	8	3	107	1	MR	4	4
619	PI	566150	Gong Da Mai	China	3	2	109	2	MSI	4	4
620	PI	566151	Kang Da Mai	China	3	2	105	2	I	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]	Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
621	PI 566152	Zi Mi Da Mai	China	7	2	109	2	MSI	23	4
622	PI 566159	Da Mai	China	3	2	109	2	MSI	23	4
623	PI 566176	Juan Mang Liu Leng Lu Ren	China	1	2	105	H	MSI	23	4
624	PI 566180	Huo Liao Tou Mi Mai	China	1	2	105	H	MSI	23	4
625	PI 566200	117537	China	3	2	101	2	MSI	23	4
626	PI 566316	Tang Xi Liuo Jiao Da Mai	China	7	3	105	2	MS	12	4
627	PI 566341	Mi Mai	China	1	3	105	1	MS	23	4
628	PI 566342	Zao Shu	China	1	2	109	1	S	23	4
629	PI 566343	Zao Shu	China	1	2	107	1	S	23	4
630	PI 566348	117870	China	1	2	105	2	I	4	4
631	PI 566349	Chun An Luo Mai	China	7	2	107	2	I	23	4
632	PI 566350	117881	China	1	2	107	H	I	4	4
633	PI 566351	Hai Yan Mao Chong Da Mai	China	1	2	106	H	MS	4	4
634	PI 566352	117888	China	1	2	102	H	MS	4	4
635	PI 566353	Xin Chang Song Hua Mi Mai	China	1	2	100	H	I	4	4
636	PI 566354	Yu Yao Mi Mai	China	3	2	99	2	I	23	4
637	PI 566355	Yu Yao Chi Hong Xian Zi	China	7	2	107	2	MSI	4	4
638	PI 566356	San Men Luo Da Mai	China	1	3	101	2	MSI	4	4
639	PI 566357	Lin Hai Ghuang Tou Da Mai	China	6	3	99	2	I	4	4
640	PI 566358	Huang Yan Si Leng Luo Mai	China	1	2	101	2	MSI	4	4
641	PI 566359	Tian Tai Da Mai Mi	China	4	2	102	2	MSI	4	4
642	PI 566361	Wen Cheng Huang Mai	China	3	2	101	2	I	4	4
643	PI 566362	117926	China	3	3	102	2	I	4	4
644	PI 566365	Yong Jia Dai Mao Da Mai	China	3	3	100	H	MSI	4	4
645	PI 566366	117934	China	3	3	105	2	MS	4	4
646	PI 566371	Jing Ning Qing Pi	China	3	2	105	2	I	4	4
647	PI 566373	117960	China	3	3	94	1	S	4	4
648	PI 566374	117963	China	3	2	105	2	MS	4	4
649	PI 566375	117964	China	3	2	105	2	I	4	23
650	PI 566376	Lin An Luo Mai	China	3	2	102	2	I	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
651	PI	566377	Tong Lu Yang Da Mai	China	3	3	100	2	MSI	23	4
652	PI	566378	117968	China	3	3	105	H	S	4	4
653	PI	566379	Hai Yan Luo Da Mai	China	3	2	101	2	MS	23	4
654	PI	566381	Xian Ju Duan Liu Leng	China	3	2	102	2	I	23	4
655	PI	566382	Yu Huan Liu Leng Mi Mai	China	3	2	101	2	I	23	4
656	PI	566386	Le Qing Fang Tou Luo Mai	China	3	2	107	2	MSI	23	4
657	PI	566387	118001	China	3	2	105	2	MS	23	4
658	PI	566388	Tai Shun Liu Leng Mi Mai	China	3	3	100	2	S	23	4
659	PI	566389	118003	China	3	3	107	2	MSI	23	23
660	PI	566392	118016	China	4	2	105	2	I	23	4
661	PI	566393	Mi Mai	China	3	2	105	2	I	4	4
662	PI	566394	Mi Mai	China	3	2	105	2	MS	23	4
663	PI	566401	San Yue Huang	China	4	2	99	2	I	23	4
664	PI	566402	062 Mi Yu Mai	China	3	2	102	2	MS	4	4
665	PI	566403	Quan Mang Da Mai	China	1	3	104	H	I	23	4
666	PI	566404	Xin 48 Mi Da Mai	China	3	2	105	2	I	4	234
667	PI	566411	Lao Wu Hu Xu Mai	China	4	2	103	2	IMS	4	4
668	PI	566413	Lao Wu Hu Xu Mai	China	3	2	104	2	MRI	4	4
669	PI	566414	Wu Mai Zi	China	3	2	102	0	R	4	4
670	PI	566417	Hie Qing Ke	China	7	3	109	1	IMS	4	4
671	PI	566444	Da Mai	China	3	2	101	2	I	4	4
672	PI	566445	Yan Mai	China	3	2	104	2	I	4	4
673	PI	566451	Zou Xian Song Mang Da Mai	China	3	2	102	H	IMS	4	4
674	PI	566453	Ju Xian Luo Da Mai	China	1	2	112	2	MS	4	4
675	PI	566454	Tai Zhang Tu Tou Da Mai	China	3	2	109	2	MRI	4	4
676	PI	566455	Lai Wu Zi Mi Da Mai	China	7	2	111	2	MSI	4	4
677	PI	566456	Zhu Cheng Mi Da Mai	China	3	2	109	2	MS	4	4
678	PI	566458	Bo Shan Dong Mi Da Mai	China	3	2	109	2	MSI	4	4
679	PI	566459	Xin Tai Mi Da Mai	China	3	2	109	2	IMS	4	4
680	PI	566479	Qing Ba Gu Tao	China	4	2	100	2	I	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
681	PI	566482	Ba Gu Tao	China	1	2	96	1	S	4	4
682	PI	566483	Wu Mi Mai	China	7	2	105	2	S	4	4
683	PI	566484	Mi Da Mi	China	3	2	101	2	IMS	4	4
684	PI	566485	Shuan Shu Qu	China	3	2	102	2	I	4	4
685	PI	566486	Hei Da Mai	China	7	2	102	2	MRI	4	4
686	PI	566505	Lu Quan 13 Hao	China	1	2	101	2	I	23	4
687	PI	566516	Lu Quan 37 Hao	China	3	3	105	2	MSI	4	4
688	PI	566519	Jiu Jiu Mai	China	3	2	99	H	MSI	4	4
689	PI	566533	Mi Da Mai	China	3	3	108	2	I	23	4
690	PI	573759	RNB2	Nepal	4	2	105	0	MSI	3C	4
691	PI	573761	RNB4	Nepal	4	2	102	0	I	4	4
692	PI	573763	RNB6	Nepal	3	2	102	1	I	4	4
693	PI	573764	RNB7	Nepal	4	2	104	0	MS	23	4
694	PI	573765	RNB8	Nepal	4	2	102	2	MSI	3C	4
695	PI	573766	RNB9	Nepal	4	2	101	10	MR/S	3C	4
696	PI	573767	RNB10	Nepal	4	2	101	1	I	4	4
697	PI	573768	RNB11	Nepal	4	2	101	1	MSI	23	4
698	PI	573771	RNB14	Nepal	3	3	101	1	MR	3C	4
699	PI	573776	RNB19	Nepal	4	2	99	1	I	4	4
700	PI	573777	RNB20	Nepal	3	2	100	H1	MRI	4	4
701	PI	573792	RNB35	Nepal	3	2	102	1	MS	4	234
702	PI	573803	RNB46	Nepal	3	2	105	2	MS	4	4
703	PI	573804	RNB52a	Nepal	4	2	107	1	IMS	4	4
704	PI	573805	RNB53	Nepal	4	2	105	1	MSI	4	4
705	PI	573811	RNB60	Nepal	3	2	100	2	IMS	4	4
706	PI	573813	RNB63	Nepal	3	2	96	2	MRI	4	4
707	PI	573814	RNB64	Nepal	1	2	99	1	R	4	4
708	PI	573817	RNB67	Nepal	3	2	100	1	MRR	4	4
709	PI	573818	RNB68	Nepal	3	2	99	1	MRR	4	4
710	PI	573819	RNB69	Nepal	3	2	99	1	MRR	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]	Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
711	PI 573820	RNB70	Nepal	3	2	99	1	MRR	4	4
712	PI 573822	RNB72	Nepal	3	2	99	2	I	4	4
713	PI 573825	RNB76	Nepal	3	2	102	2	MSI	4	4
714	PI 573826	RNB77	Nepal	1	2	97	H1	MSI	4	4
715	PI 573827	RNB78	Nepal	1	2	96	H1	MS	4	4
716	PI 573828	RNB79	Nepal	3	2	96	H1	MS	4	4
717	PI 573831	RNB83	Nepal	1	2	97	H1	S	4	4
718	PI 573834	RNB86	Nepal	1	2	96	H1	S	4	4
719	PI 573836	RNB88	Nepal	3	2	98	H1	S	4	4
720	PI 573837	RNB90	Nepal	3	2	96	H1	MS	4	4
721	PI 573839	RNB92	Nepal	3	2	99	H1	S	4	4
722	PI 573840	RNB93	Nepal	3	2	101	2	I	4	4
723	PI 573851	RNB105	Nepal	3	2	104	1	MRI	4	4
724	PI 573852	RNB106	Nepal	3	2	105	H	IMR	4	4
725	PI 57353	RNB107	Nepal	3	2	104	1	I	4	4
726	PI 573861	RNB95	Nepal	3	2	96	H1	S	4	4
727	PI 573869	RNB123	Nepal	3	2	99	2	MSI	4	4
728	PI 573881	RNB135	Nepal	3	2	99	2	IMS	4	4
729	PI 573913	RNB167	Nepal	3	2	104	2	MSI	4	4
730	PI 573915	RNB169	Nepal	3	2	102	2	MS	4	4
731	PI 573917	RNB171	Nepal	3	2	101	2	IMS	4	4
732	PI 573918	RNB172	Nepal	3	2	101	2	MRI	4	4
733	PI 573920	RNB174	Nepal	3	2	99	2	MRI	4	4
734	PI 573921	RNB175	Nepal	3	2	99	2	I	4	4
735	PI 573944	RNB198	Nepal	1	2	99	1	MR	4	4
736	PI 573950	RNB205	Nepal	1	2	99	1	MR	4	4
737	PI 573951	RNB206	Nepal	1	2	99	2	MS	4	4
738	PI 573952	RNB207	Nepal	1	2	98	2	MS	4	4
739	PI 573953	RNB208	Nepal	3	2	97	2	S	4	4
740	PI 573954	RNB209	Nepal	1	2	100	1	MR	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
741	PI	573957	RNB212	Nepal	1	3	101	2	IMS	4	4
742	PI	573958	RNB214	Nepal	1	2	100	1	MR/I	4	4
743	PI	573960	RNB217	Nepal	3	2	97	1	MR	4	4
744	PI	573961	RNB218	Nepal	3	3	96	1	IMS	4	4
745	PI	573962	RNB219	Nepal	3	3	100	2	MSI	4	4
746	PI	573966	RNB224	Nepal	3	3	100	1	MS	4	4
747	PI	573967	RNB225	Nepal	3	2	99	1	MS	4	4
748	PI	573968	RNB226	Nepal	3	2	100	1	S	4	4
749	PI	573969	RNB227	Nepal	1	2	99	1	MSI	4	4
750	PI	573970	RNB228	Nepal	1	3	100	1	S	4	4
751	PI	573971	RNB229	Nepal	4	2	100	1	MS	4	4
752	PI	573973	RNB231	Nepal	1	2	101	1	S	4	4
753	PI	573980	RNB238	Nepal	1	2	102	1	S	4	4
754	PI	573981	RNB239	Nepal	3	2	102	1	MS	4	4
755	PI	573982	RNB240	Nepal	1	2	100	1	MS	4	4
756	PI	573983	RNB241	Nepal	3	3	101	1	MS	4	4
757	PI	573984	RNB243	Nepal	3	3	100	1	MS	4	4
758	PI	573987	RNB248	Nepal	3	3	100	1	MS	4	4
759	PI	573988	RNB249	Nepal	3	2	100	1	MS	4	4
760	PI	573989	RNB250	Nepal	3	3	101	1	MS	4	4
761	PI	573990	RNB251	Nepal	3	2	101	1	IMS	4	4
762	PI	573991	RNB252	Nepal	3	2	102	1	MSI	4	4
763	PI	573995	RNB256	Nepal	3	3	100	2	MSI	4	4
764	PI	573999	RNB260	Nepal	3	3	102	2	MS	4	4
765	PI	574002	RNB263	Nepal	3	3	99	H12	IMS	4	4
766	PI	574008	RNB270	Nepal	4	2	99	H	MR/MS	4	4
767	PI	574011	RNB273	Nepal	3	2	104	2	I	4	4
768	PI	574012	RNB274	Nepal	1	2	99	H1	MS	4	4
769	PI	574018	RNB281	Nepal	4	2	99	2	I	4	4
770	PI	574024	RNB287	Nepal	4	2	99	2	MS	23	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]	Genotype Description[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
771	PI 574027	RNB290	Nepal	3	2	100	H1	MRI	3C	4
772	PI 574028	RNB291	Nepal	4	3	101	H	MS	23C	4
773	PI 574029	RNB292	Nepal	4	2	100	0	MSI	23	4
774	PI 574030	RNB293	Nepal	4	3	100	0	I	4	4
775	PI 574033	RNB296	Nepal	4	3	100	0	IMS	3C	4
776	PI 574034	RNB297	Nepal	3	2	101	H	I	3C	4
777	PI 574035	RNB298	Nepal	4	2	98	H1	MS	4	4
778	PI 574036	RNB299	Nepal	3	2	97	H1	MS	4	4
779	PI 574038	RNB301	Nepal	4	2	99	0	MS	4	4
780	PI 574041	RNB304	Nepal	3	2	99	1	MR/S	4	4
781	PI 574042	RNB305	Nepal	1	2	99	2	S/MR	4	4
782	PI 574043	RNB306	Nepal	3	2	100	1	MR/1S	4	4
783	PI 574046	RNB309	Nepal	3	2	99	1	MRR	4	4
784	PI 574047	RNB310	Nepal	4	2	101	1	MR	4	4
785	PI 574048	RNB311	Nepal	3	2	100	1	MR/1S	4	4
786	PI 574054	RNB318	Nepal	3	2	101	H1	MR	4	4
787	PI 574059	RNB326	Nepal	3	2	99	2	MS	3C	4
788	PI 574064	RNB334	Nepal	4	3	101	H1	I	4	4
789	PI 574065	RNB335	Nepal	4	3	100	2	MS	3C	4
790	PI 574067	RNB338	Nepal	4	3	100	2	MS	3C	4
791	PI 574076	RNB349	Nepal	3	3	99	2	S	4	4
792	PI 574081	RNB361	Nepal	3	3	99	1	I	4	4
793	PI 574084	RNB366	Nepal	3	3	104	2	MS	4	4
794	PI 574085	RNB367	Nepal	4	3	104	H	MSI	4	4
795	PI 574099	RNB384	Nepal	3	3	99	1	MS	4	4
796	PI 574105	RNB391	Nepal	7	3	101	2	MS	4	4
797	PI 574107	RNB394	Nepal	7	3	102	2	S	4	4
798	PI 574108	RNB396	Nepal	7	3	102	2	S	4	4
799	PI 574109	RNB401	Nepal	7	3	102	2	S	4	4

Table A-2 (cont.). Seedling reaction of 807 hulless barley lines from the world collection to races 8 and 30 of leaf rust and powdery mildew, characterization for seed color, starch type, heading date, and awn type.

Entry	Accession[1]		Genotype name or designation[2]	Origin[3]	Seed Color[4]	Starch Type[5]	Heading Date[6]	Awn Type[7]	Mil[8]	LR 30[9]	LR 8
800	PI	574110	RNB405	Nepal	7	3	107	1	S	4	4
801	PI	574114	RNB424	Nepal	1	3	106	H1	S	4	4
802	PI	574116	RNB426	Nepal	7	3	104	1	MS	4	4
803	PI	574122	RNB438	Nepal	1	3	107	1	MRI	4	4
804	PI	574124	RNB440	Nepal	7	3	105	2	MSI	4	4
805	PI	574128	RNB448	Nepal	3	3	102	2	MSI	23C	4
806	PI	574134	RNB455	Nepal	3	3	102	2	MS	3C	4
807	PI	574135	RNB456	Nepal	3	3	102	2	S	23C	4

VITA

Robert Leroy Paris was born in New Albany, Indiana on July 22, 1970. He attended Portland Christian Elementary and High School in Louisville, Kentucky where he graduated in May, 1988. He entered Berea College, located in Berea, Kentucky in August 1988, and earned a Bachelor of Science degree in Agriculture in May 1992. During his time at Berea College, he met Deborah Ann Clark of Gap Mills, West Virginia, and was married in June 1993. After farming for two years, he accepted a graduate research assistantship at the University of Tennessee, Knoxville in the Department of Plant and Soil Science in August 1994. He received a Master of Science degree under the guidance of Dr. Fred Allen in May 1997. The title of the thesis was: Water use efficiency of two soybean cultivars differing in leaflet orientation. In January 1997 he accepted a position as a research associate at Virginia Polytechnic Institute and Sate University in the Department of Crop and Soil Environmental Sciences at Blacksburg, Virginia. There he was in charge of the hulless barley breeding program and earned a Ph.D. in plant breeding and genetics in the department of Crop and Soil Environmental Sciences in April 2000. The title of the dissertation was: Potential of hulless winter barley as an improved feed crop