EFFECTS OF PEARLING LEVEL AND GENOTYPE ON PHYSICAL GRAIN CHARACTERISTICS, COMPOSITION, AND TECHNOLOGICAL AND SENSORY PROPERTIES OF SELECTED WESTERN CANADIAN BARLEY VARIETIES

BY

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ABSTRACT

Limited information exists regarding the effects of light pearling on the properties of physical grain characteristics, composition, and technological and sensory properties of selected varieties of Western Canadian barley especially hulless barley genotypes with modified starch characteristics. Nine barley genotypes with different hull (hulled and hulless) and starch characteristics (normal, waxy, and high amylose (HA)) were pearled to three differing levels. Scanning electron micrographs showed that the pericarp, testa, aleurone, and subaleurone layers were completely removed in heavily pearled barley whereas only a few outer layers were removed in minimally pearled barley. Waxy starch genotype Fibar and HA starch genotypes, SH99250 & SB94893 contained high levels of soluble β-glucan (9-11%). Waxy starch genotypes exhibited higher β-glucan solubility when cooked compared to normal and HA starch genotypes. However, HA starch genotypes had lower *in vitro* starch digestibility which may provide a lower glycemic response in humans.

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CHD	coronary heart disease
HB	hulless barley
HA	high amylose
PL	pearling level
HMG-CoA	3-hydroxy-3-methylglutaryl coenzyme A
GI	glycemic index
SEM	scanning electron microscope
AACC	American Association of Cereal Chemists
ANOVA	analysis of variance
SPSS	Statistical Program for Social Sciences
SDI	starch digestion index

1.0. INTRODUCTION

Barley (*Hordeum vulgare* L.) is an ancient cereal grain that was formerly a staple food but over time its consumption has decreased in favor of wheat. Today, the use of barley in human foods is limited, but many African and Asian countries continue to have a long tradition of utilizing barley in the diet. In North America, barley is primarily used for animal feed and for the production of malt although small quantities of pearled barley are used in soups, stews, porridges, and baby foods. With greater awareness of the health benefits associated with barley and whole grains, there is the potential to restore barley's status in the North American diet.

Research has shown that whole grains which are known to have high levels of dietary fibre may play a critical role in improving human health by reducing the incidence of hyperlipidemia, obesity, diabetes, hypertension, coronary heart disease (CHD), gastrointestinal disorders, gallstones, appendicitis, diverticular disease of the colon, bowel polyps, hemorrhoids, and colorectal cancer (Keogh et al. 2007; Behall et al. 2004; Kim et al. 2006). Canada's Food Guide recommends consumption of 5-12 servings of grain products per day and that at least 50% of these servings should be from a whole grain source (Health Canada, 2008). In the United States, food products falling under the classification of a whole grain can carry a health claim stating that, "Diets rich in whole grain foods and other plant foods and low in total fat, saturated fat, and cholesterol may reduce the risk of heart disease and certain cancers" (USDA, 2006). At present, this health claim has not been approved for use in Canada but it is currently being reviewed by Health Canada (2009). As consumers become more familiar with whole grain

products, increased acceptance will likely follow leading to increased demand for whole grain products, such as minimally processed barley.

Whole grain barley is an excellent source of β-glucan soluble fibre, arabinoxylans, protein, vitamins, minerals, and phytonutrients, such as phenolic acids. Barley is similar to other cereal grains in terms of caloric value, vitamin and mineral composition, and protein quality but contains higher levels of soluble fibre (β-glucans) (Miller & Fulcher, 1994) than other cereals with the exception of oats. Also, compared to other cereals, the distribution of β-glucan in barley is more homogeneous throughout the kernel. Thus from a nutritional perspective, barley has some positive advantages over other cereal grains due to its increased level and more uniform distribution of β-glucans. The United States Food and Drug Administration (USDA) has allowed a health claim on foods from barley that contain 0.75g of β-glucan per serving to state that they can reduce the risk of CHD when consumed as part of a diet low in saturated fat and cholesterol (2005). At present this claim is not permitted in Canada but is under review by Health Canada (2009).

Another important development influencing the renewed interest in barley as a food ingredient is the release of hulless barley (HB) varieties. In HB, the hull is loose and becomes separated from the kernel during threshing thereby eliminating the need to remove the hull prior to processing the grain. These HB varieties have been noted for containing higher levels of β-glucan and protein than hulled varieties.

Within HB genotypes, new varieties have been developed that possess different starch characteristics. Access to a wide range of barley genotypes varying in starch characteristics is advantageous to the food industry as it allows for a range of barley

ingredients with different functionalities. Modified barley genotypes include zero and low amylose (waxy) starch and high amylose (HA) starch genotypes. Modified starch genotypes are considered more functional than normal starch (unmodified) genotypes due to the high swelling power and the colloidal stability of waxy starch genotypes and the unique gelling and film forming properties of HA starch genotypes (Jadhav et al. 1998). In addition, barley with modified starch characteristics tends to be higher in β-glucans and total dietary fibre than normal starch genotypes (Izydorczyk & Dexter, 2004).

The traditional and most common method of processing barley for food use is pearling which involves the gradual removal of the outer layers of the grain including the hull by an abrasive action. The majority of commercially available barley has been pearled to a high degree resulting in a white colored, quick cooking product. Pearling allows barley to have a longer shelf-life due to removal of the germ which causes rancidity, as well as, it removes phenolic acids and enzymes which darken barley. Typically, pot barley has 15% of its outer layers removed whereas pearl barley is classified as any barley having more than 15% outer layers removed and commonly has upwards of 45% removed (Yeung & Vasanthan, 2001). Thus, both pot and pearled barley do not meet the classification of a whole grain. Consumers desire foods with higher levels of dietary fibre and are more accepting of whole grains but there is no commercially available whole grain pearled barley to fulfill this need. Thus, there is an opportunity for minimally pearled barley in the marketplace. Limited information exists regarding the effect of minimal pearling on the physical, compositional, and cooking properties of barley, especially HB varieties and genotypes with modified starch characteristics. It was the purpose of this research therefore to compare the effects of pearling level (PL) and

genotype and their interaction on the properties of selected varieties of Western Canadian barley. The development of HB and novel types of barley with modified starch characteristics and high levels of dietary fibre (soluble β-glucan) paired with the application of minimal processing techniques may play a critical role in the expansion of barley for food use.

The specific objectives of this research were:

1. To investigate the effects of PL and genotype on physical grain characteristics and composition of uncooked kernels and technological and sensory properties of cooked kernels of selected Western Canadian barley varieties.
2. To compare the quality attributes of selected Western Canadian barley varieties pearled to differing degrees.
    a. To determine differences between pearled hulled and hulless barley for physical grain characteristics and composition of uncooked kernels and technological and sensory properties of cooked kernels.
    b. To determine differences among pearled barley varieties with varying amylose content for physical grain characteristics and composition of uncooked kernels and technological and sensory properties of cooked kernels.

2.0. LITERATURE REVIEW

2.1. History and production of barley

Barley (*Hordeum vulgare* L.) is one of the most widely cultivated cereals due to its ability to be grown in a wide range of environments. Evidence shows barley was first cultivated in the fertile crescent of the Middle East in approximately 10,000 BC and is very similar to barley presently grown (Harlan, 1979). Columbus is credited with the introduction of barley to the New World (Thacher, 1903). Barley grows particularly well under relatively cool temperatures where the ripening season is long, where soil is well drained but not sandy, and where rainfall is moderate (Newman & Newman, 2006). It is considered to be the most alkali, cold, salt, and drought tolerant among the small grain cereal crops but does not thrive as well in wet or acidic soils (Poehlman, 1985). Barley matures early and uses a low quantity of water which explains its high tolerance to adverse conditions. Barley can withstand high temperatures but only if the humidity is low. When both temperature and humidity are high, it does not grow well. Winter production of barley is possible at low latitudes and barley is less winter hardy than wheat and rye but more hardy than oats (Wiebe, 1978).

Barley is utilized for three primary uses: malting, animal feed, and food for human consumption. In ancient times, barley was widely used in the human diet but consumption patterns changed as other cereal grains became more abundant. Individuals began to prefer grains that produced brighter colored breads and barley was regarded as ‘poor man’s bread’ because it produced noticeably darker colored bread (Newman & Newman, 2006). Globally, consumers are becoming more aware of health benefits associated with barley and are more accepting of darker colored breads. As a result, there

is high potential for barley to regain its status as a food ingredient. It should be noted however, there are countries where barley is still an important staple for food use including Tibet, Korea, Mongolia, and many African and Asian countries (McIntosh, 1995). For example, Morocco is the largest per capita food user of barley, in which it is usually incorporated into soups, bread, and porridge (Ashman & Beckley, 2006). Also, Japan uses barley in a number of food applications including miso, tea, shochu, and as a rice extender (Ashman & Beckley, 2006). Pearled barley is the most common form of barley food available in North America (Newman & Newman, 2006).

Barley is the fourth largest cereal crop grown worldwide, with approximately 136 million tonnes produced per year (FAO, 2009). Worldwide, Canada is the third largest producer of barley with an annual average production of 9.9 million tonnes (Statistics Canada, 2010). However, in 2010, Statistics Canada reported that Canadian barley production was 28% below the 10 year average due to record high levels of rainfall. Statistics Canada (2010) reported that approximately 92% of barley produced in Canada was grown in the Prairie provinces: Alberta (59.6%), Saskatchewan (25.5%), and Manitoba (6.4%) (Table 2.1). However, most of this is used for animal feed, with small amounts being used for malt, and a very small amount for direct human consumption. Current estimates for annual production of HB in Canada are estimated at approximately 8,000 to 12,000 tonnes (D. Munro, Canadian Wheat Board, personal communication, March 24, 2011).

Table 2.1. 2010 Barley production in Canada

	Area Harvested (‘000 hectares)	**Yield** (kilogram/ hectare)	**Production** (‘000 tonnes)	**Produced** (%)
Canada	2387	3,200	7,605	100
British Columbia	16	1,900	30	0.3
Alberta	1,265	3,600	4,529	59.6
Saskatchewan	751	2,600	1,938	25.5
Manitoba	164	3,000	488	6.4
Ontario	73	3,500	257	3.4
Quebec	86	3,000	260	3.4
New Brunswick	11	3,100	35	0.5
Nova Scotia	3	3,200	8	0.1
Prince Edward Island	20	3,000	61	0.8

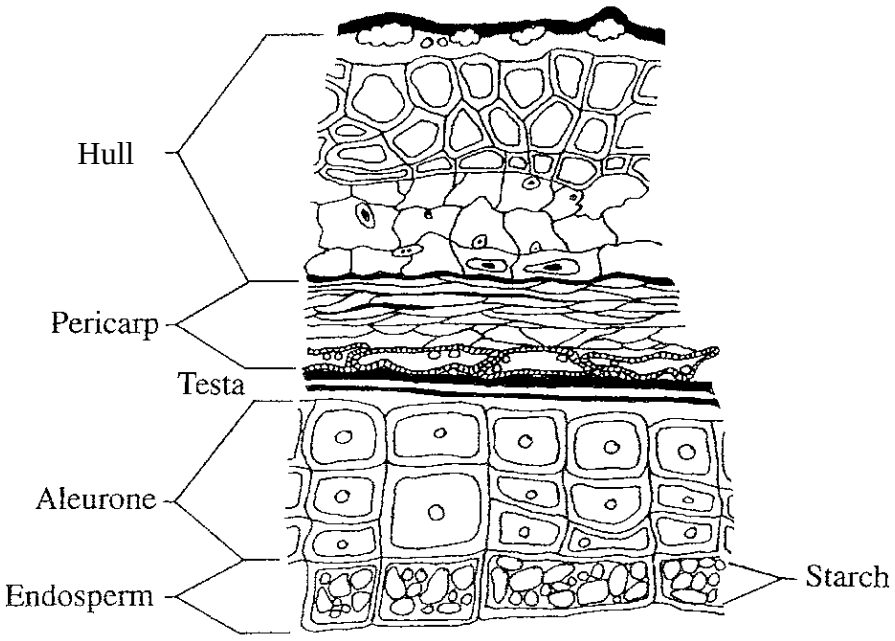
Statistics Canada (2010).

2.2. Barley kernel structure

The barley kernel is spindle shaped with a shallow crease running along the ventral side of the kernel (Figure 2.1). In hulled barley, the outermost layer is the hull but in HB, the hull is absent as it falls off during threshing. Beneath the hull is the caryopsis, a one seeded fruit in which the pericarp is fused to the testa. Within the testa, the endosperm is bound on the outside by the aleurone layer. At the basal end of the barley kernel, the embryo is found.

The hull is the outermost component of the barley grain and is commonly damaged at the apex and base of the kernel due to threshing (Briggs, 1978). The hull surface is usually pale yellow, patterned with wrinkles, and composed of two different leaf-like structures, the lemma and palea. The lemma covers the dorsal, rounded side of the grain, whereas the palea is indented over the shallow crease on the ventral side.

Figure 2.1. Tissues of a typical barley kernel



Adapted from Kent (1983).

The pericarp makes up approximately 2% of the kernel weight and is the tissue to which the lemma and palea adhere to (Briggs, 1978). It is made up of the epidermis, hypodermis, cross cells, and tube cells. During development, the pericarp becomes compressed due to the tight adherence of the hull. However, in HB, air spaces commonly occur between the husk and the pericarp because hull is loosel
result, lessens the compression on the pericarp. Thus, in HB, the pericarp is less compressed and more robust compared to hulled barley. The pericarp is closely adherent to the testa all over the grain except at the apex.

The testa, commonly referred to as the seedcoat, is composed of two lipid layers that effectively separate the exterior from the interior of the grain by forming a semi-

permeable membrane that limits the movement of solutes and water. The testa comprises anywhere from 1-3% of the total kernel weight (Briggs, 1978).

The endosperm is made up of the dead starchy endosperm tissue and the living aleurone layer which consists of a layer of cuboidal cells which covers the starchy endosperm except at the ventral furrow and makes up anywhere from 5-10% of the total kernel weight (Briggs, 1978). In mature grain, the cells of the aleurone layer remain alive and are capable of synthesizing and secreting a diverse range of enzymatic proteins needed for the digestive depolymerization of the stored polymers in the starchy endosperm. The starchy endosperm is the largest tissue and comprises approximately 75-80% of the barley kernel (Izydorczyk & Dexter, 2004). Within the starchy endosperm, the starch grains are embedded within a proteinaceous matrix.

The embryo, which is comprised of the axis and scutellum, is located on the dorsal side of the barley kernel at the attachment end. It comprises approximately 2.5% of the total kernel weight (Izydorczyk & Dexter, 2004).

2.3. Barley genetics

Cultivated barley is a diploid possessing seven pairs of chromosomes that have the ability to control the expression of a wide range of morphological and physiological characteristics. Over 1,200 traits have been identified from barley chromosomes due to its diploid and self-fertile nature, ease of hybridization, and its many easily classified heritable characters (Nilan & Ullrich, 1993). There is a great amount of genetic diversity within the characteristics of barley cultivars, some traits include hulled or hulless, number of fertile rows, or differing starch characteristics. Other important genetic traits that may

affect barley quality include size of endosperm, length of awn, and β-glucan and lysine content (McIntosh et al. 1995).

Barley can be either hulled or hulless which is a characteristic that is established during the maturation of the grain. In hulled barley, the hull remains attached during threshing, whereas, for HB the hull is separated from the kernel during threshing. Ideally, HB should have no more than 5% adhering hulls (Bhatty, 1999). Hulled barley is used mainly for malting and feed, whereas, HB is preferred for both animal and human food. Use of hulled barley for human consumption requires hull removal which is generally done by pearling. HB is more desirable for human food consumption because it does not require dehulling/pearling which reduces processing time and cost if a flaked product or flour is desired. Although grain yield of HB may be about 10-12% less than hulled barley due to the loss of the hull in the field, the overall grain volume of hulled barley is subsequently decreased by the need for the pearling process (McIntosh et al. 1995). Typically, HB possesses higher β-glucan and starch content since the hull does not contain starch or β-glucans which increases the overall content of these components (Table 2.2).

Table 2.2. Chemical composition of barley with differing hull characteristics (%)

Chemical Constituent	Hulless	Hulled
Starch	--- 60[d] 62[e] 54.2-59.8[f]	60-65[a,b,c] 53.7[d] 59[e] 40-50[f]
Sugars	1.6[d]	1.4[d]
Proteins	--- --- 17.6[g] 16.5[d] 11.9[e] 9.6-12.2[f]	10-12[a] 8-15[b] 12.4[g] 15.9[d] 9.7[e] 7.5-11.5[f]
Lipids	--- 1.5-2.4[f]	2-3[a,b,c] 1.4-3.5[f]
Total Dietary Fibre	13.8[d] 14.7[e]	18.6[d] 20.6[e]
β-glucans	3.3-8.1[c] 3.4-6.2[f] 5.6[d] 5.9[e]	3.6-6.1[b] 2.2-4.6[f] 5.2[d] 5.2[e]
Arabinoxylans	--- 4.5[d] 5.2[e] 1.6[e]	4.4-7.8[b] 6.5[d] 8.1[e] 4.1[e]
Minerals (ash)	--- 2.1[d,e]	2-3[a,b,c] 2.5-2.8[d,e]

[a] MacGregor & Fincher, 1998
[b] Jadhav et al. 1998
[c] Izydorczyk & Dexter, 2004
[d] Xue et al. 1997
[e] Andersson et al. 1999
[f] Jood & Kalra, 2001
[g] Briggs, 1978

Barley possesses three spikelets and whether or not they are all fertile determines whether it is classified as six row or two row. In six row types, all three spikelets are fertile, whereas, in two row barley cultivars only the middle spikelet is fertile. In six row genotypes, the kernels tend to be less homogeneous compared to two row genotypes due to the fact that the kernels have less room to develop which causes some twisting in the

kernels located in the lateral spikelets. Also, the kernel size tends to be larger for two row varieties because they have more room to develop. Regardless of number of rows, where the kernel is located on the spikelet has an affect on kernel size with larger kernels generally occurring in the middle of the spike and smaller ones near the ends. According to Izydorczyk and Dexter (2004), two row barley is preferred for pearling due to the fact it is typically more plump and homogeneous in kernel size than six row barley (Izydorcyzk & Dexter, 2004). Thus, the number of rows may play a critical role in the physical properties of the barley kernel and the ease of processing. However, from a compositional perspective, the number of rows may not play a significant role.

The ratio of amylose to amylopectin in the barley kernel also differs greatly among cultivars. Table 2.3 lists the level of amylose present in the various barley types according to starch classification. The genotypes with modified starch characteristics tend to be higher in β-glucans and total dietary fibre than normal starch genotypes (Izydorczyk & Dexter, 2004; Xue et al. 1991). Also, starch composition has a significant effect on the *in vitro* digestibility where waxy starch is more susceptible to enzymatic hydrolysis and HA barley is less susceptible (Izydorczyk & Dexter, 2004). However, more research *in vivo* needs to be conducted to confirm this. In a study where waxy barley was fed to chickens, there was no difference in starch digestibility when compared to normal barley (Moss et al. 1983). Research has also shown that HA barley can significantly reduce the serum cholesterol of chickens and this was associated with the presence of soluble dietary fibre or linked to the formation of amylose lipid complexes (Newman & Newman, 1991). Functionally, waxy starch swells to a greater extent due to higher amylopectin levels present than normal starch genotypes (Goering et al. 1973). On the other hand, HA

genotypes swell less than normal starch genotypes due to lower levels of amylopectin (Morrison et al. 1986). Thus, the ratio of amylopectin present within the barley kernel affects the compositional and the swelling properties of barley starch.

Table 2.3. Definition of classification of starch characteristics

Classification	Level of Amylose (%)
Zero amylose	0
Waxy	1-5
Normal	20-30
High amylose	30-45

Adapted from Izydorczyk et al. 2000.

2.4. Barley composition

The outermost layers of the kernel, the husk and pericarp, consist primarily of insoluble fibre and minerals. The lipid layers of the testa contain fatty acids and have wax containing alkanes, sterols, esters and n-alkyl resorcinol (Briggs, 1974). In the aleurone layer, arabinoxylans, β-glucans, protein, triglycerides, phenolic acids, minerals, vitamins (thiamin, riboflavin, niacin, pantothenic acid, tocotrienols, and biotin), and sugars (sucrose, raffinose, stachyose, verbascose, and fructans) are found (MacGregor, 1998). The majority of the endosperm is composed of starch but also contains a large amount of protein which is embedded within the structure of the starch. β-glucans, arabinoxylans, glucomannans, celluloses, proteins, and phenolic constituents make up the majority of the endosperm (Jadhav et al. 1998). Also, small amounts of lipids and minerals are found within the endosperm. The embryo is rich in protein, lipids, ash, and sugars (sucrose, raffinose, and fructosans). Within the embryo, the majority of the cell walls of the scutellum are composed of hemicellulose and some phenolic acids. Few or no starch

granules are present but protein bodies, lipids, Golgi bodies, mitochondria, and rough endoplasmic reticulum have been noted.

The chemical composition of barley varies depending on both genetic and environmental factors, as well as, the method used to analyze the constituent. Genetic factors that affect the chemical composition of barley include the differing hull and starch characteristics. Environmental factors that can affect the chemical composition include variables, such as temperature, water supply, day length, and availability of soil minerals (Jadhav et al. 1998). The range in chemical constituents found in barley with differing hull characteristics is given in Table 2.2. The chemical composition of HB with differing starch characteristics is shown in Table 2.4.

Table 2.4. Chemical composition of hulless barley with differing starch characteristics (%)

Chemical Constituent	**Zero Amylose**	**Waxy**	**Normal**	**High Amylose**
Starch	58.5	58.2-64.7	59.9-64.4	56.0
Protein	13.8	11.8-13.0	11.5-13.2	14.0
Lipids	6.6	6.1-6.8	5.2-5.7	5.0
β-glucans	7.3	6.4-7.4	3.7-6.3	7.0-7.7
Minerals (Ash)	1.9	1.8-2.1	1.8-1.9	2.3

Adapted from Li et al. 2001.

2.4.1. Carbohydrates

Carbohydrates account for the majority of the chemical constituents within barley. The concentration of starch is inversely related to the total dietary fibre content (Newman & Newman, 1991). Barley also contains small amounts of free simple sugars (sucrose, fructose, maltose, glucose) and oligosaccharides (raffinose, fructans).

Two types of polysaccharides make up starch, amylopectin and amylose. The structure of amylose is essentially linear, whereas, amylopectin is a much larger molecule that is highly branched. In barley with normal starch characteristics, the amylose to amylopectin ratio is 20-30%:70-80%. Recently, barley breeders have developed genotypes with varying amylose to amylopectin ratios (Table 2.3) by altering one of two genes (Izydorczyk & Dexter, 2004). By varying the ratio of amylose to amylopectin, the chemical constituents within the barley kernel are altered (Table 2.4). β-glucan levels tend to be higher in waxy and HA starch genotypes compared to barley with normal starch characteristics (Li et al. 2001).

Waxy barley possesses higher viscosity and gelatinization temperatures than normal barley which can be attributed to the higher amylopectin levels found in these genotypes (Bhatty & Rossnagel, 1999; Czuchjowska et al. 1998). Waxy barley starch, containing low levels of amylose and lipids, swell to a greater extent than normal starch and have high colloidal stability (Goering et al. 1973). In contrast, HA barley starches do not swell as much as normal barley starches which suggests that the amylopectin fraction is responsible for the swelling power of a given starch (Morrison et al. 1986). The higher swelling capacity of waxy barley starch may cause gumminess in some food products which may limit their use in certain food applications. Gels made from normal and HA barley starch (hardness ranged from 5.2 – 9.5 N) were significantly harder than gels made from waxy barley starch (<0.6 N) (Czuchajowska et al. 1998). Also during storage, gels made from normal barley increased in hardness from 4.1 N to 7.2 N, whereas, gels made from HA barley increased in hardness from 6.6 N to 9.2 N (Czuchajowska et al. 1998). The higher gel hardness found for HA barley could be attributed to its higher amylose

content which enables the gel to pack tighter due to the linear structure of amylose. Bhatty and Rossnagel (1999) also found that zero amylose HB had higher paste clarity compared to corn and potato starch which would make it more useful in certain applications. Thus, the functional properties of the various barley starches are significantly different which may be useful in formulating specific food products.

Starch is also made up of two granule sizes, large lenticular (A-type, 10-25 μm) and small spherical (B-type, <10 μm) (MacGregor & Fincher, 1993). The small granules account for up to 90% of the total starch granules but only 10% of the total starch weight, whereas, the large granules constitute the remaining 10% of the starch but constitute up to 90% of the total starch weight (Goering et al. 1973). By varying the starch characteristics, the starch granule size is also altered. In waxy barley genotypes, there is a higher number of starch granules due to the presence of numerous small granules compared to barley with normal starch characteristics (Tester and Morrison, 1992). In HA barley starch, the A-type granules are smaller and the B-type granules are larger than normal barley starch, which results in a more uniform size distribution (Morrison et al. 1986). Thus, the ratio of amylose to amylopectin affects the size distribution of the starch granules within the endosperm.

2.4.2. Protein

The protein content of barley typically ranges from 8-15% (Table 2.2). The protein quality within barley is relatively high, with a protein digestibility corrected amino acid score of 90 (ADSA, 2007). The distribution of the protein fractions within the barley kernel is as follows: albumins (20-30%), globulins (5-10%), hordeins (20-30%), and glutelins (20-40%) (Simmonds, 1978). In terms of amino acid composition, lysine is

the limiting amino acid followed by methonine, threonine, and tryptophan (Hockett, 1991).

2.4.3. Dietary Fibre

Dietary fibre is the edible part of the plant that is resistant to digestion and absorption in the small intestine with complete or partial fermentation in the large intestine (AACC, 2001). Barley contains both water soluble and insoluble dietary fibre. The cell walls of the starchy endosperm contain approximately 75% β-glucans and 20% arabinoxylans, whereas, the aleurone cell walls contain roughly 26% β-glucans and 71% arabinoxylans. The remaining constituents of fibre are only present in small amounts within the kernel; however, insoluble fibre is present in the hull of hulled genotypes. Thus, when barley is subjected to pearling or is a HB genotype, the level of insoluble fibre present is noticeably decreased. The total dietary fibre found in barley typically ranges from 14-21%, although, the total dietary fibre of barley will vary with genotype and environment, as will the ratio of soluble to insoluble fibre. Bhatty and Rossnagel (1998) found that the β-glucan content of ten cultivars of Canadian HB was positively correlated with total dietary fibre ($r = 0.81$, $p<0.01$) and soluble fibre ($r = 0.86$, $p<0.01$).

β-Glucans are linear homopolysaccharides composed of D-glucopyranosyl residues that are in consecutive (1→4) linked blocks that are separated by (1→3) linkages. β-Glucans tend to have an irregular shape due to presence of (1→3) linkages at irregular intervals which reduces their ability to pack into stable, regular aggregates (Buliga et al. 1986). Due to their structural features, β-glucans tend to form a viscous solution when dissolved with water. Depending on genotype and environment, β-glucan content typically varies from 3-8% (Table 2.2). However, improved genotypes with

varying starch characteristics have been developed that possess levels as high as 15%. Bhatty (1999) reported that the β-glucan content and viscosity levels increase due to enhanced synthesis during dry environmental conditions.

Arabinoxylans consist of (1→4)-β-*D*-xylan chains with α-L-arabinofuranose residues attached by (1→2) or (1→3) linkages to xylose residues. The degree and pattern of substitution of arabinose residues, as well as, presence of covalent cross linkages via phenolic acid bridges determine the solubility of arabinoxylans creating both water soluble and insoluble forms (Izydorczyk and Biliaderis, 2006). The α-L-arabinofuranose residues protruding from the xylan chain suppresses the interchain linking system, thus, making the polymer only partially soluble in water (Atkins, 1992). The presence of segments of unsubstituted xylose residues in the polymer chains may increase the potential of arabinoxylans to form intermolecular aggregates which may lead to either precipitation of polymer chains or an increase in viscosity (Izydorczyk and Biliaderis, 2006). Arabinoxylan chains can also be cross-linked with phenolic acids, such as ferulic acid (MacGregor, 1993). Typically, the content of arabinoxylans ranges from 4.5-8% (Table 2.2). It should be noted that unlike in β-glucans, environmental factors have a larger effect than genotype variation on arabinoxylan content (Henry, 1986). The majority of arabinoxylans are found in the outer layers of the kernel (pericarp/testa) and the remainder are located within aleurone and endosperm fractions (Izydorczyk and Biliaderis, 2006).

Insoluble fibre is concentrated in the hull, pericarp, testa, and aleurone layers and is composed of cellulose, hemicelluloses, insoluble arabinoxylans, and lignins. Cellulose is a linear (1→4)-β-D-glucan polymer that is crystalline, strong and is resistant to

hydrolysis, whereas, hemicellulose has a random, amorphous structure with little strength. Lignin adds strength to cell walls by covalently linking with hemicellulose and filling in spaces in the cell wall (Chabannes, 2001).

2.3.4. Lipids

Lipid content of barley varies between 2-3% (Table 2.2). However, there are cultivars that contain up to 7% lipids. The major fatty acids present in barley are linoleic (55%), palmitic (21%), oleic (18%), and α-linolenic acids (6%) (McIntosh et al. 1995). The barley kernel also contains free sterols, sterol esters, diglycerides, free fatty acids, and hydrocarbons (Newman & McGuire, 1985).

Tocols (tocopherols and tocotrienols) are biologically active compounds found in barley oil that consist of four isomers: α, β, γ, and δ. Total tocol concentrations range from 42-80 mg/kg (Peterson & Qureshi, 1993). Tocols act as an antioxidant by inhibiting lipid peroxidation in biological membranes (Jadhav et al. 1998). Peterson and Qureshi (1993) suggest that barley is one of the richest sources of tocols not only because of its high concentration but also the favorable distribution of the most biologically active isomers (α-tocopherols and α-tocotrienols).

2.3.5. Phenolic acids

Phenolic acids, known for their antioxidant ability, are present in barley primarily as caffeic, p-coumaric, ferulic, vanillic, and sinapic acids (Madhujith et al. 2006). Generally, total phenolic content in barley ranges from 600 – 1400 µg/g (Holtekjolen et al. 2006). The majority of phenolic acids are located in the outer layers of the barley kernel, such as the pericarp, testa, and aleurone layers (Madhujith et al. 2006).

Predominately, ferulic acid (90%) is the phenolic acid present but in a bound form, ester-linked to polymers in the plant cell wall (Holtekjolen et al. 2006). Free phenolic acids account for only a small percentage of the total phenolic acid content.

2.3.6. Vitamins and minerals

The gross mineral matter of barley (2-3%) is the "ash" which is the portion that remains after burning a sample until it is free of carbon (Table 2.2). The predominant minerals present are phosphorus, calcium, and potassium (Newman & Newman, 1991). Smaller amounts of sulfur and magnesium are present, as well as many other trace elements.

Barley is an excellent source of B-complex vitamins: thiamin, pyridoxine, riboflavin, and pantothenic acid. Also, barley contains a significant amount of niacin but the majority of it is bound by protein making it biologically unavailable. A small amount of vitamin E and small amounts of folate and biotin are also found in barley (Newman & McGuire, 1985).

2.5. Health benefits associated with barley

Research has shown that barley can aid in heart health, blood sugar management, weight management, and cancer prevention (Keogh et al. 2007; Yokoyama & Shao, 2006; Kim et al. 2006; Ludwig et al. 1999; Cummings, 1997). The USDA (2005) *Dietary Guidelines for Americans* recommends consuming at least three servings of whole grain foods per day. Similarly, Canada's Food Guide recommends consuming at least three to six whole grain servings per day (Health Canada, 2008). There is potential for minimally processed barley to be considered a whole grain since it contains the same relative

proportion of the principal anatomical components that exist in the original kernel. The USDA (2005) has allowed food products that contain at least 0.75 g of soluble β-glucan fibre per serving to carry the health claim that the associated food may decrease the risk of CHD. The USDA (2006) concluded that the daily consumption of 3 g of soluble β-glucan from whole grain barley and dry milled barley products such as flakes, grits, and flour would produce the same cholesterol lowering effect as oat products (lower plasma total cholesterol by 5-8%). At present, this health claim has not been approved for use in Canada but it is currently being reviewed by Health Canada with an anticipated decision expected in 2012 (Mike Leslie, Alberta Barley Commission, personal communication).

2.5.1. Hypocholesterolemic effect

Barley has been associated with reducing cholesterol and plasma triglyceride levels in both animal models and human clinical trials (Kalra & Jood 2000; Behall et al. 2004; Hallfrisch et al. 2003). Research has shown that the beneficial effects are due to the presence of many chemical constituents, including soluble fibre (β-glucans and water soluble arabinoxylans), tocols, α-linolenic acid, and phenolic acids in barley. Behall et al. (2004) administered 3 or 6 g of barley β-glucan per day for 5 weeks to 25 mildly hypercholesterolemic subjects and observed a 5% and 6% reduction in serum cholesterol levels, respectively. Soluble fibre may lower the level of serum lipids via several mechanisms. Soluble fibre increases the viscosity of the contents in the small intestine, thereby limiting digestion and absorption of lipids (McIntosh, 1995). Soluble fibre is also fermented by colonic bacteria into short chain fatty acids that may inhibit cholesterol synthesis (Glore et al. 1994). In addition, soluble fibre alters bile acid metabolism and sequesters bile acids thereby increasing their elimination (McIntosh, 1995). Soluble fibre

may also influence insulin and glucagon secretion both of which are associated with lipid metabolism (McIntosh, 1995). However, it has been observed that barley genotypes that have been treated with β-glucanase still exhibit hypocholesterolemic effects, which suggest that there are other active constituents besides soluble β-glucan responsible for the effect (Newman et al. 1992). For example, tocols within barley have been credited for their hypocholesterolemic effect. Qureshi et al. (1991) suggest that tocols have the ability to decrease the activity of the rate limiting enzyme 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA) reductase, a key enzyme in cholesterol synthesis. Peterson and Qureshi (1993) found a decrease in HMG-CoA reductase activity combined with an increase in cholesterol 7 α-hydroxylase activity (enzyme that breaks cholesterol in the synthesis of bile acids) when they fed chickens β-glucan from barley in the absence of any significant tocol concentration. Thus, these findings would suggest tocols are not solely responsible for the reduction of HMG-CoA reductase. α-Linolenic acid is also a chemical constituent that has been identified for its ability to reduce the activity of HMG-CoA reductase present (Qureshi et al. 1986). In addition, Madjuith and Shahidi (2007) have suggested that phenolic acids chelate with copper which aids in protection against the prevalence of low density lipoprotein cholesterol. Thus, phenolic acids may also play a role in enhancing the hypocholesterolemic effect.

2.5.2. Hypoglycemic effect

Evidence shows that barley has a hypoglycemic effect that is indicated by a low glycemic and insulin response in individuals (Thondre & Henry, 2009, King et al. 2008, Cavallero et al. 2002). Epidemiological data suggests that a diet characterized by a low glycemic index (GI) reduces insulin resistance which may have a potential role against

the development on type 2 diabetes mellitus (Pick et al. 1998). GI is the rise in blood glucose after eating a food compared to white bread or a glucose standard. Barley has a GI of <55, thereby making it a food with a low GI (Anderson, 2002). Foster-Powell et al. (2002) reported that whole HB had a GI of 39 ± 6. The low GI of barley is attributed to the high level of β-glucan present. A linear decrease in GI was found for bread containing increasing β-glucan levels (Cavallero et al. 2002). Kim et al. (2006) reported that an acute reduction in glycemic response in ten overweight women required the consumption of at least 2 g of barley β-glucan per meal.

The ratio of amylopectin to amylose influences the GI of foods; if a high level of amylose is present, there tends to be a lower GI (Liu, 2002; Kabir et al. 1997). This mechanism is thought to be related to the tight, compact structure of amylose, which physically slows down enzymatic reactions, whereas, amylopectin with its branched structure is open to enzymatic attack and is easily digested. Thus, the HA genotypes may be more useful than other genotypes in reducing the rise in blood sugars in the body when the food is consumed. Keogh et al. (2007) examined the hypoglycemic effect of HA barley flour on 14 healthy women compared to wheat flour. Mean areas under the curve for glucose and insulin were 22% and 32% lower for barley than for wheat containing diets, respectively. Rendell et al. (2005) conducted a study comparing the glycemic response of waxy HB to oats in non-diabetic and type 2 diabetic subjects. In both groups of subjects, the increase in both blood glucose and insulin levels after consuming the barley was significantly lower compared to the oats and the control. Urooj et al. (1998) reported that glucose responses of 15 type 2 diabetic patients to breads containing 10% whole barley or 15% pearled barley were significantly lower than glycemic responses to

white bread. The asymmetrical structure of β-glucan can increase the viscosity of a meal and delay starch hydrolysis and absorption of glucose into the blood (Trogh et al. 2007). This results in improved insulin and postprandial glucose responses and in turn may prevent or reduce hyperinsulinemia and hyperglycemia (Wood, 2007; Lifschitz et al. 2002).

2.5.3. Effects on satiety

Another health benefit associated with barley (β-glucans) is the regulation of satiety resulting in decreased energy intake (Kim et al. 2006). With lower caloric intake due to increased satiety, proper weight management in obese or overweight individuals may be more easily achieved. The suggested mechanisms of β-glucan for satiety effects include malabsorption, increased gastric distention, regulation of satiety hormones, decreased rate of gastric emptying, and reduced glycemic responses (Pereira et al. 2001; Ludwig et al. 1999). Increased fibre intake has been correlated with lower body mass index values (Ludwig et al. 1999). Through regular consumption of barley, increased satiety may be experienced and may aid in weight management.

2.5.4. Anticarcinogenic effects

Dietary fibre (soluble and insoluble) has three main mechanisms for reducing or preventing cancer: bulking, binding and fermentation. In terms of a bulking effect, dietary fibre dilutes mutagens and other toxic metabolites in the gut and decreases the transit time required, thereby decreasing the epithelial exposure to toxic and mutagenic contents (McIntosh & Jacobs, 2002). Cummings (1997) found that risk of colon cancer was inversely proportional to the daily amount of stools in a comparative study of 23

population groups. Dietary fibre also has the ability to bind certain metabolites (carcinogens, secondary bile acids) and removes them from the bowel, which decreases the risk of cancer (McIntosh & Jacobs, 2002). In addition, fermentation of dietary fibre generates short chain fatty acids in the large bowel and these can increase the moisture, decrease pH, and decrease solubility and activity of some mutagens and carcinogens (McIntosh & Jacobs, 2002). Thus, a high level of dietary fibre, which is characteristic of barley, plays a critical role in the reduction or prevention of cancer.

Antioxidants delay the onset or slow down the rate of oxidation in the body. Oxidative stress occurs when the production of reactive oxygen species override the antioxidant capability of the target cell and has been implicated in the formation of cancer (Slavin et al. 2000). Barley contains a high level of antioxidants in the form of phenolic acids. The potentially anti-carcinogenic mechanism of these phenolic acids involves the induction of detoxification systems in the cell (Slavin et al. 2000).

2.6. Pearling of barley

Pearling is an abrasive scouring process that gradually removes the outer grain tissues, the hull, pericarp, testa, aleurone and/or outer endosperm layers and embryo, leaving behind the endosperm (Figure 2.1). The hull on barley is strongly attached to the pericarp which makes it difficult to remove. Thus, barley must undergo pearling to remove the hull. Even HB must undergo minimal pearling to remove any adhering hulls. When examining the pearling process, Pederson et al. (1989) found that the hull, pericarp, and testa makes up the majority of the 0-11% pearled fraction and the germ and aleurone makes up a large portion of the 11-25% pearled fraction. Typically, the hull, pericarp,

and testa are relatively easily removed, whereas, the removal of the aleurone layer is more difficult (McIntosh at al. 1995).

Most pearling equipment consists of one or a number of carborundum or emory stones depending on the size of the equipment, and they which revolve rapidly within a perforated cylinder or enclosed chamber. The outer layers of the barley are then gradually removed by rubbing against the stones and the perforated cylinder. The length of time that the barley is left in the pearler determines how much of the outer tissues of the kernel are removed. In industry, the 'degree of pearling' is a term that is commonly used but its meaning differs in different regions of the world. In North America, 25% pearled means that 25% of the original kernel has been removed, whereas, in Japan, the equivalant would be 75% pearled. In North America, pearled food barley is available as pot barley (15% pearled) or pearl barley (>15% pearled) (Yeung & Vasanthan, 2001). Ideally, barley for pearling should be uniform in size, free from discoloration, plump, white, medium kernel hardness, and have thin hulls or be hulless (Kent, 1983).

The starch characteristics of barley can affect kernel hardness, thereby affecting the pearling properties (Edney, 2002). Waxy HB kernels tend to be more desirable for pearling because they produce more intact kernels with brighter color and desirable texture after cooking compared to hulled or HB normal starch genotypes (Edney, 2002).

In general, pearling has a significant effect on the cooking properties of barley. Whole grain barley contains the germ portion of the kernel, whereas this component is removed when kernels have been subjected to a moderate level of pearling. The germ contains most of the lipids found within the barley kernel. Relatively high levels of these lipids are found in the unsaturated form making them prone to oxidation resulting in

rancid odour development (Morrison, 1993). Thus, the shelf-life and overall quality of moderately pearled barley may be superior to whole grain or lightly pearled barley. Another benefit derived from pearling is the removal of phenolic acids and enzymes, such as polyphenol oxidase and peroxidase, which are located in the outer layers of the barley kernel and tend to darken barley over time (Yeung & Vasanthan, 2001). On the other hand, the removal of these components can also be a disadvantage from a nutritional standpoint.

Also, as the level of pearling increases, there is a corresponding rise in water uptake resulting in a softer and stickier product (Klamczynski et al. 1998; Park at al. 1989). Park et al. (1989) reported that the rate of water uptake was significantly faster for 30% pearled kernels compared to whole grain kernels. The viscosity and gelatinization temperature of barley also increased with higher levels of pearling and this is due to the increase in starch concentration within the pearled kernels (Czuchajowska et al. 1998). The viscosity of whole grain barley flour was 680 BU compared to 970 BU in barley pearled to 40% (Czuchajowska et al. 1998). Research also shows that whole grain kernels have a higher hardness value than those that have been pearled, independent of genotype and starch characteristics (Klamczynski et al. 1998). As pearling level increased from 10% to 40%, the firmness of cooked barley, measured with a texture analyzer, significantly decreased from 28 N to 8.7 N after 30 min of cooking (Klamczynski et al. 1998).

3.0. MATERIALS & METHODS

3.1. Selection of barley genotypes

Nine genotypes of Western Canadian barley differing in hull characteristics and starch characteristics (normal, waxy, and HA starch) from the 2006 crop year were evaluated (Table 3.1). All samples were registered varieties with the exception of the two HA starch barley genotypes which were experimental lines developed at the Crop Development Centre, University of Saskatchewan. The two hulled varieties, Legacy and Metcalfe were chosen on the basis that they are the most commonly cultivated six row and two row varieties in Canada, respectively. Both varieties are typically used for malting purposes but Legacy is also used as a rice extender and for shochu production in the Japanese market.

Table 3.1. Description of barley genotypes

Genotype	Hull	Starch	Number of Rows	Year Registered	Sourced From
Legacy	Hulled	Normal	6	2002	CWB[b]
Metcalfe	Hulled	Normal	2	1997	CWB
McGwire	HB[a]	Normal	2	1999	CWB
Alamo	HB	Waxy	2	1999	Proven Seeds, SK
Fibar	HB	Waxy	2	2003	Proven Seeds, SK
Enduro	HB	Waxy	2	2007	Proven Seeds, SK
Rattan	HB	Waxy	2	2003	Proven Seeds, SK
SH99250	HB	High amylose	2	N/A	CDC[c]
SB94893	HB	High amylose	6	N/A	CDC

[a] HB refers to hulless barley
[b] CWB refers to the Canadian Wheat Board, Winnipeg
[c] CDC refers to the Crop Development Centre, University of Saskatchewan, Saskatoon

3.2. Pearling technique

Barley samples were passed through a cartage dockage tester (Cartage Day International, Minneapolis, MN) to clean the samples of any debris. The barley kernels were pearled in batches of 180 g using a Satake Grain Testing Mill (model TM-05, Satake, Tokyo, Japan) fitted with an abrasive roller and a 1 mm screen. The samples were pearled to three pearling levels defined by the amount of kernel removed during the pearling process (Table 3.2). The two hulled barley samples were pearled an additional 5% compared to the HB samples in order to account for the presence of hulls.

Table 3.2. Amount of kernel removed (%) at each pearling level

Genotype[a]	**Weight of Kernel Removed (%)**			
	PL0	**PL1**	**PL2**	**PL3**
Legacy	0	10	15	30
AC Metcalfe	0	10	15	30
CDC McGwire	0	5	10	25
CDC Alamo	0	5	10	25
CDC Fibar	0	5	10	25
Enduro	0	5	10	25
CDC Rattan	0	5	10	25
CDC SH99250	0	5	10	25
CDC SB94893	0	5	10	25

[a] refers to the research centre that developed the variety; AC- Agriculture Canada; CDC- Crop Development Centre

Pearling was repeated to obtain approximately 5 kg of pearled grain for each genotype and each pearling level. Pearled samples were stored at 4ºC until required for analyses. The desired level of pearling was calculated by determining the weight of the sample after pearling and dividing it by the initial weight. Following pearling, the barley sample was put in a small sieve (#14, 1.4 mm opening) to remove any loose bran and a large sieve (4.5) to remove shorts and thins.

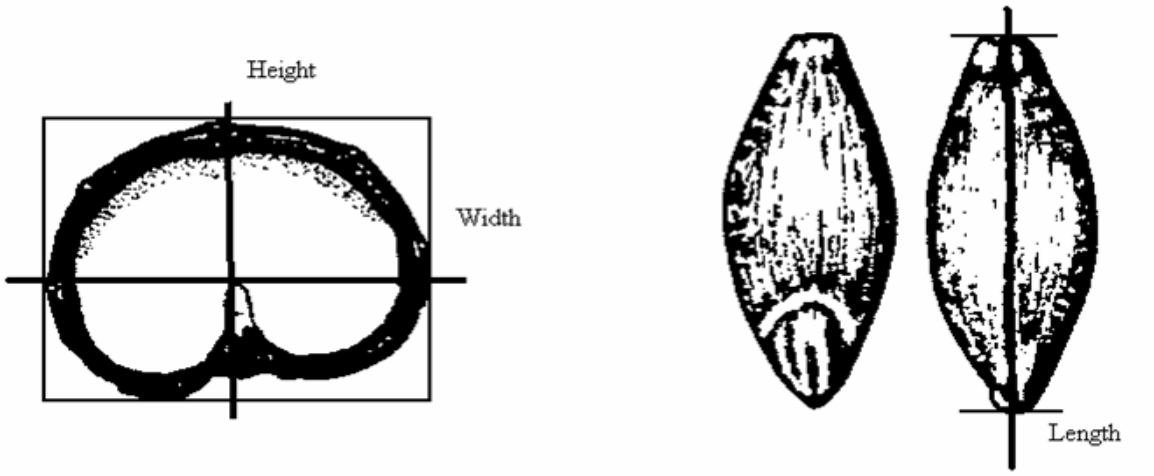
3.3. Physical grain characteristics

3.3.1. Kernel size and shape determination

Scanning electron microscopy (SEM) was used to examine the manner in which the outer layers of the kernel were removed during pearling. Kernels were fractured transversely and a small incision, only slightly beyond the aleurone layer, was made with a scalpel (No. 3 blade, Fisher Scientific) in the middle of the kernel, across the ventral crease. The scored kernels were broken by hand and half kernels were mounted, with the fractured surface facing up, onto aluminum stubs with Leit-C conductive carbon cement (Neubauer, Germany) and were allowed to dry and set for 24 h. The mounted samples were placed in a Hummer VII (Anatech, Ltd., Hayward, CA, USA) sputter coater and coated with 50 nm of gold. Three individual barley kernels per genotype at each pearling level were examined with a JEOL JSM-6400 scanning electron microscope at an accelerating voltage of 10 kV and photographed on Kodak TMAX 100 Black and White Professional 120 roll film.

Image analysis was performed on 100 barley kernels using a scanner (Microtek ScanMaker 4) equipped with Microtek Scan Wizard software (v. 2.60 2000). For each sample, the image of 100 barley kernels placed vertically with the crease facing downward on the scanner glass was captured. Length and width were calculated by measuring the major and minor axis of the kernel (Figure 3.1). Height was measured manually with a ruler from pictures taken from SEM micrographs in triplicate.

Figure 3.1. Graphical representation of barley kernel shape parameters



Adapted from Kirby (2002).

3.3.2. Kernel hardness & level of broken kernels

Grain hardness was determined by measuring the energy required to crush the grain, with harder grain requiring more force (Camm & Rossnagel, 2005). Hardness index of 300 pearled kernels was determined using the Single Kernel Characterization System (SKCS) and results were reported as an average. Values from the SKCS range from 0 to 100, with 0 indicating softest and 100 indicating hardest texture.

The level of broken kernels was determined by manually removing broken kernels present in a 30 g subsample. Broken kernels were classified as any piece less than 2/3 of the whole pearled kernel (Edney et al. 2002). The weight of broken kernels remaining divided by the original weight was expressed as the percentage of broken kernels (%).

3.3.3. Brightness

Brightness of the pearled barley samples was determined using a colorimeter (Minolta CR 310, Japan) according to the L*a*b* color system where L* represents the

level of brightness present ranging from 0 (black) to 100 (white). The granular material attachment (CR-A50) designed for the colorimeter was filled to the top with grain (~30 g), the lid was screwed on, and brightness was measured through the glass. Two measurements on each repetition for every sample were recorded.

3.4. Barley composition

Moisture content was determined using a Fisher Scientific Isotemp oven according to AACC method 44-15A (AACC, 1999). Moisture content was required in order to calculate compositional values on a dry weight basis. For many of the compositional analyses, a UV/Visible spectrophotometer (Ultraspec 2100 Pro) and a centrifuge (Beckman Avanti Centrifuge; rotor JA-17) were required. All analyses were performed in duplicate on ground barley samples obtained by grinding approximately 200 g of barley in a cyclone lab sample mill (Udy Corp, Fort Collins, CO, USA).

3.4.1. Total starch

Total starch content of the barley samples was performed according to AACC method 76-13 (AACC, 1999) using the Megazyme total starch assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland). Results were expressed as a percentage (%).

3.4.2. Protein

Total nitrogen content was determined by combustion nitrogen analysis using a Dumas CAN Analyser (LECO Model FP-528, MI, USA) using AACC method 46-12 (AACC, 1999). A factor of 6.25 was used to convert total nitrogen to protein content. Results were expressed as a percentage (%).

3.4.3. Ash

Barley samples were incinerated at 560°C according to AACC basic method 08-01 (AACC, 1999) for gravimetric ash determination. Results were expressed as a percentage (%).

3.4.4. β-Glucan and arabinoxylans

β-Glucan content of the barley samples was analyzed according to AACC method 32-23 (AACC, 1999) using the mixed linkage β-glucan assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland, UK) according to McCleary (1985). Results were expressed as a percentage (%).

Arabinoxylan content was determined colorimetrically using phoroglucinol according to the method of Douglas (1981). Results were expressed as a percentage (%).

3.4.5. Free phenolic acids

Level of free phenolic acids in acidified methanol was determined from a modified method of Beta (2005). Methanol (80%) is the most efficient solvent to extract phenolic acids from barley (Zielinski & Kozlowska, 2000). Acidified methanol (2 mL) was added to ground barley samples (100 mg) and shaken for two h to extract free phenolic acids. Tubes were centrifuged for 15 min (4000 RPM) to obtain a clear supernatant. All samples were diluted (two fold) with acidified methanol. Folin-Ciocalteau reagent was used to measure differences in free phenolic acids present based on color and sodium carbonate was also added. Tubes were then covered and allowed to sit for one hour at which time tubes were read on a spectrophotometer (725 nm). Ferulic acid was used to form a standard curve and results were expressed in µg/mg.

3.5. Determination of technological and sensory properties of cooked barley

3.5.1. Cooking method

A cooking method was developed based on the method of Klamczynski et al. (1998). In 1 L Pyrex beakers fitted with Kimax covers, 50 g of barley was added to 500 mL of boiling water (Kaur & Singh, 2007). After cooking, the kernels were immediately drained using a standard kitchen sieve and cooled for 15 min. Preliminary tests indicated that most barley kernels were cooked after 30 min of boiling in excess of water but some genotypes required longer cook times. The kernels were considered cooked when no white, opaque spots were visible upon squeezing of kernels between two transparent plastic plates. Two additional cooking times, 20 and 40 min, were added to cover differences in optimum cooking times among genotypes. After measuring water uptake, brightness and firmess, approximately 30 g of cooked barley was put in the freezer (-18ºC) to be freeze-dried for β-glucan solubility.

3.5.2. Water uptake

Water uptake was calculated on kernels cooked for 20, 30, and 40 min by subtracting the weight of the cooked kernels from the original weight of the sample (50 g). Results were expressed as amount of water absorbed per 100 g of sample.

3.5.3. Instrumental determination of brightness of cooked barley kernels

Brightness was determined on barley cooked for 20, 30, and 40 min using a colorimeter (Minolta CR 310, Japan) according to the L*a*b* color system. Color analysis for cooked samples was determined in same manner as for raw samples.

3.5.4. Instrumental determination of firmness of cooked barley kernels

Texture of barley kernels cooked for 20, 30, and 40 min was measured using a texture analyser (TA HD Plus, Stable Micro Systems, Surrey, UK) equipped with a pasta firmness/stickiness rig using Exponent Stable Microsystems software (v. 4.0.6.0). Twelve kernels of cooked barley were placed vertically on surface with the crease downward in a grid (4x3). Firmness was determined by compressing the barley kernels to 50% of their original thickness according to the method of Klamczynski et al. (1998). The test speed was set at 0.1 mm/s (Bargale & Irudagoraj, 1995) and trigger force was set at 0.05 N using a 30 kg load cell. The force required to compress the sample was expressed in Newtons (N). Appendix A illustrates a typical peak force curve and summarizes the texture analyzer settings used for analyzing the barley kernels.

3.5.5. β-Glucan loss during cooking and solubility of β-glucans in cooked barley kernels

Analysis of β-glucan loss and solubility on McGwire and Fibar was conducted at all three cooking times (20, 30, and 40 min) to determine if there were differences due to cooking time. Similar results were observed across the three cooking times for five genotypes (Legacy, McGwire, Fibar, Rattan, and SB94893) representing a range of hull and starch characteristics so 30 min was chosen for analysis of the remaining genotypes. β-glucan solubility was analysed by determining both the total β-glucan and soluble β-glucan present. Total β-glucan content of the cooked, ground, freeze-dried barley samples and raw ground barley samples was performed according to AACC method 32-23 (AACC, 1999) using the Megazyme mixed linkage β-glucan assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland) according to McCleary (1985). β-Glucan loss was calculated as the total β-glucan content in uncooked barley kernels subtracted by

total β-glucan content in cooked barley kernels. Soluble β-glucan content was determined on the ground barley samples by shaking the cooked, ground, freeze-dried barley samples and raw ground barley samples for 2 h in a shaking water bath (45°C) with use of a mechanical shaker every 15 min for 5 min. The same β-glucan determination assay as described previously was also used on extracted barley samples to determine soluble β-glucan present. Results for β-glucan solubility were expressed as a percentage (%).

3.5.6. *In vitro* starch digestibility

Starch digestibility rate was determined on cooked barley at PL2 digested for 15, 30, 60, and 120 min. Barley genotypes, Legacy, McGwire, Fibar, Rattan, and SB94893 were analyzed as they represent a wide range of hull and starch characteristics. PL2 was selected to examine the effect of time on the digestibility of starch since it represented the midpoint of the pearling levels examined in the study. The digestion rate chosen was 30 min because a large amount of starch was digested at this length of time.

To prepare the samples, barley genotypes, Legacy, McGwire, Fibar, Rattan, and SB94893 from PL1, PL2, and PL3 were cooked optimally (31 – 47 min depending on genotype) as determined during sample preparation for sensory evaluation. Kernels were then placed in a strainer and rinsed with cold water for 30 s, followed by immersion in ice cold water for 10 min. Samples were then rinsed again with cold water for 30 s to remove any remaining starch from the kernel surface and drained for 5 min. The samples were placed in custard cups with lids.

To digest the starch, 25 mL of sodium phosphate buffer (pH 6.9) and 0.1 mL of porcine pancreatic α-amylase was added to 2 g of cooked barley. Samples were placed in a shaking water bath (37°C at speed 2.5) for the respective time. Tubes were then

centrifuged (4000 g for 10 min) and 10 mL of supernatant was removed and placed in a boiling water bath to deactivate the α-amylase. Next, 3 mL of each sample was removed to which 4 mL of sodium acetate buffer (200 mM, pH 4.5) and 40 µl of amyloglucosidase was added to each tube. Samples were incubated (30 min at 50°C), and were then diluted accordingly. Glucose determination reagent (3 mL) was added to the samples and incubated (20 min at 50°C) before reading on the spectrophotometer (510 nm).

3.6. Sensory evaluation of cooked barley kernels

3.6.1. Sample preparation

In 2 L Teflon lined saucepans, 95 g of pearled barley was brought to a boil in 375 mL of distilled water at high heat. Once the water was boiling, the saucepans were covered and the heat was reduced to low. The samples were cooked until optimum, defined as the point when five consecutive kernels showed no inner white core and when no white, opaque spots were visible upon squeezing of kernels between two transparent plastic plates. Cooking times ranged between 27 and 47 min depending on genotype and PL applied. The barley was then drained using a standard kitchen sieve and cooled for 10 min.

3.6.2. Panelist recruitment and training

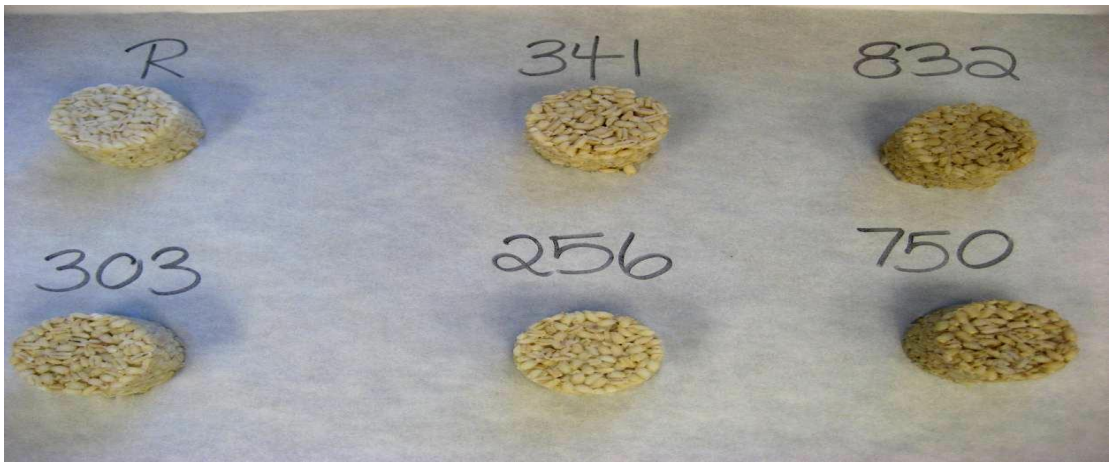
Panelists were recruited from the staff at the Canadian International Grains Institute and the Canadian Grain Commission by a letter of invitation (Appendix B1) via electronic mail. Eight panelists (7 females and 1 male) were selected to take part in the study based on their availability and interest. A letter of consent was signed by all

panelists before participation in the study (Appendix B2). Training and test sessions took place at the Canadian International Grains Institute.

Two training sessions were held to familiarize panelists with the attributes to be evaluated, the scales used to rate attributes, and the evaluation techniques. Panelists rated the samples for brightness, kernel to kernel adhesion, firmness, flavor, and overall quality using 15 cm unstructured line scales (Appendix B3). Panelists were provided with a sample of cooked commercially pearled barley (No Name, Superstore) as a reference sample. After evaluating the reference sample, the panelists agreed on the placement of the reference on each of the line scales as follows: for brightness at 10.5 cm, kernel to kernel adhesion at 10.0 cm, firmness at 9.0 cm, flavor at 4.0 cm, and overall quality at 9.0cm. Panelists were then given samples that represented the range of intensities they might encounter during the test sessions. Training continued until panelists were in agreement with each other and confident in their judgments.

To evaluate brightness and kernel to kernel adhesion, cooked barley was shaped into a cylindrical shape through manually pressing it until level into a cylinder (86 mm^2) positioned on a plate. For presentation, the cylinder was flipped over and the plastic cylinder and plate were removed to reveal the barley sample (Figure 3.2). Brightness was evaluated by visually examining the cylindrical shaped barley samples. To evaluate kernel to kernel adhesion, the cylindrical shaped barley samples were pressed with the back of a large metal spoon using a standardized procedure by the panel leader while panelists observed. Afterwards, the panelist could also press on the sample on their own to aid in analysis.

Figure 3.2. Presentation of barley samples for determination of brightness and kernel to kernel adhesion by sensory panel



R represents the reference of pearled commercial barley and the three digit random code numbers represent pearled barley samples pearled to differing degrees

To evaluate firmness, flavor, and overall quality, cooked barley (15 g) was presented to each panelist in individual, disposable plastic 125 mL cups labelled with random three digit codes. Firmness was rated according to the amount of force required to bite through four barley kernels placed between the molar teeth. Flavor was rated according to the intensity of overall flavor after chewing and swallowing four barley kernels. Overall quality was assessed by the panelists as an overall impression of all attributes combined. Comments regarding why the sample was rated this way for overall quality were also requested.

3.6.3. Test sessions

Two 30 min sessions were held per day, 11:30 am and 3:30 pm, for a total of twelve test sessions. At each test session, panelists received the reference sample (coded "R") and four or five samples coded with three digit random numbers. Barley samples

were presented in a completely randomized order. Two replications were completed. Twelve sessions were required to complete the evaluations of 9 samples x 3 pearling levels x 2 cooking replications. Panelists were provided with distilled water for rinsing between samples, a 15 cm ruler, a pencil, a plastic spoon, a napkin, and a disposable cup for water. As compensation, all panelists received a $50 gift certificate for their time and participation.

3.7. Statistical analysis

Data was analysed by two-way analysis of variance (ANOVA) using the General Linear Model (SAS, 2006). The experimental design was completely randomized with a factorial set of treatments (4 x 9) made up of four pearling levels by nine genotypes. Main effects of genotype and PL and their interaction were tested for all parameters. For all sensory data, panelists were also treated as a main effect. Since there were at least two observations for each test parameter, the residual error represented a measure of sampling error. Since the majority of results obtained were found to be statistically significant, one-way ANOVA was carried out using the Statistical Program for Social Sciences (SPSS) to examine the main effects (genotype and PL) in more detail. Tukey's test was chosen to determine the effect of each PL within each genotype and also the effect of genotype within HB varieties within each PL because variances were equal. Differences were considered significant at $P \leq 0.05$. Only HB varieties were analyzed by one-way ANOVA as hulled varieties skewed results.

4.0. RESULTS & DISCUSSION

4.1. EFFECTS OF PEARLING LEVEL AND GENOTYPE ON PHYSICAL GRAIN CHARACTERISTICS AND COMPOSITION OF BARLEY

4.1.1. Physical grain characteristics

Physical grain characteristics play an important role in determining barley quality. Size, shape, and brightness of barley are all attributes that are assessed by the end user. Thus, if any of these physical properties do not meet the end user's specifications, the barley may be rejected. In addition, kernel hardness, pearling time, and broken kernels are important processing quality characteristics.

For all physical properties (length, width, height, and brightness), genotype and PL, and their interaction were found to be significant (Appendix C). Appendix D shows where significant differences exist between both genotype and PL for physical grain characteristics.

4.1.1.1. Kernel size and shape

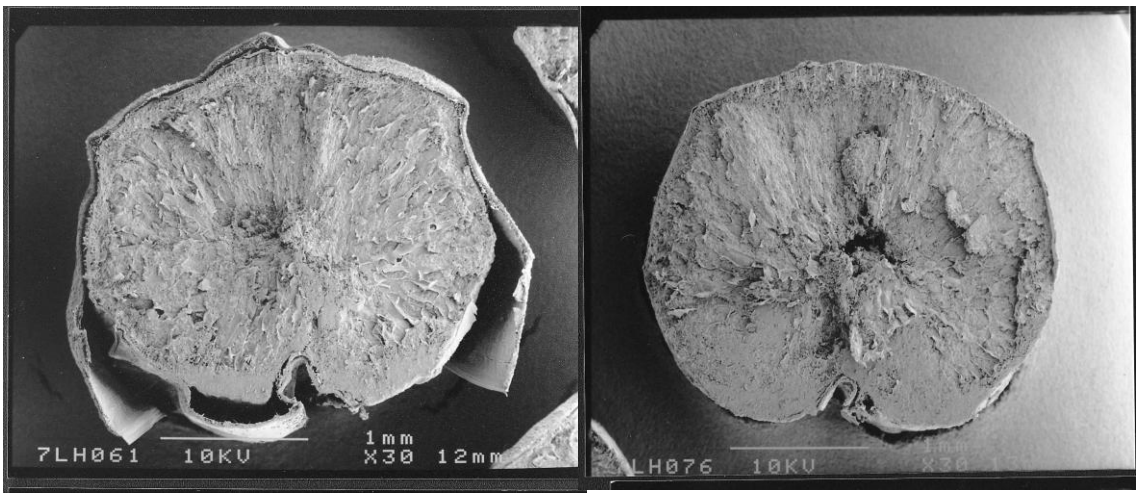
The SEM micrographs of cross sections of barley kernels before and after pearling indicate how pearling affects the size and shape of kernels and show how genotypes differ (Figure 4.1 – 4.9). Generally, as the PL increased, the cross sections of kernels became more oval because the abrasive scouring reduced the kernel height to a greater extent than its width. The reduction of kernel height was especially prominent for the HA genotypes SH99250 and SB94893 (Figure 4.8 & 4.9). The smallest reduction in kernel height was observed in the waxy genotypes Enduro and Rattan (Figure 4.6 & 4.7).

The SEM micrographs of pearled kernels demonstrate the progressive removal of the outer tissues with increasing degree of pearling. At PL1 (5% weight removal), only the most outer tissue, the pericarp, appears to be scraped off, whereas, the testa, aleurone, subaleurone layers, and the endosperm remain intact (Figure 4.10 – 4.12). The removal of the pericarp layer at PL1 was not consistent due to the irregular surface and shape of kernels and the non-uniform mode of kernel reduction during pearling. Therefore, for most genotypes at PL1, the pericarp cells were removed to a greater extent from the dorsal and ventral sides (height) of the kernel than from the cheek and crease area (width) (Figure 4.1 – 4.9). However, the six row HA genotype SB94893 at PL1 exhibited fragments of intact pericarp cells, especially in the grooves of its irregularly shaped kernels (Figure 4.9).

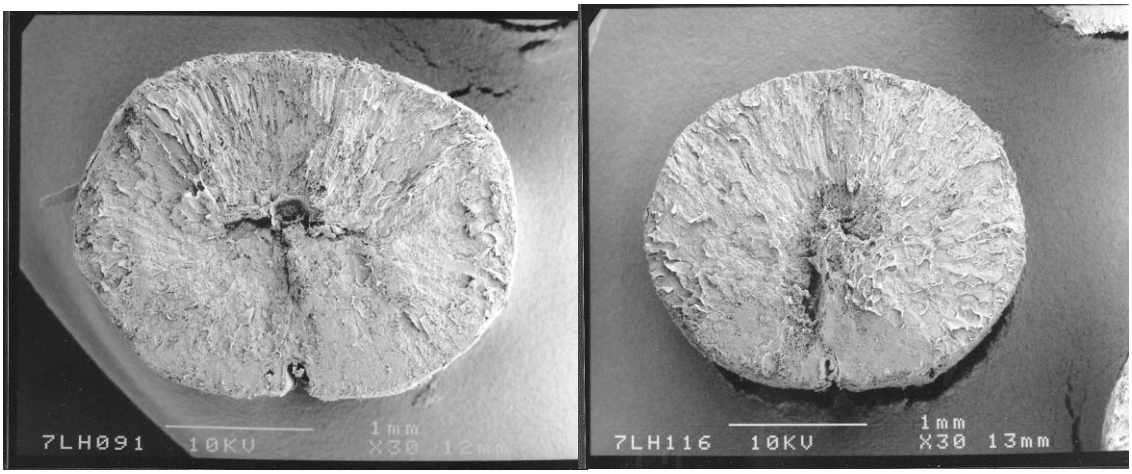
Pearling of HB to a 10% rate (PL2) caused some penetration into the aleurone and removed not only pericarp and testa but also one or even two layers of the aleurone, depending on the location along the grain periphery and/or genotype (Figure 4.10 – 4.12). Following the most intensive abrasion at PL3 (25% for HB or 30% for hulled barley), complete removal of the outer tissues, pericarp and testa, as well as, the entire aleurone and subaleurone layers has occurred (Figure 4.10 – 4.12).

Figure 4.1. Scanning electron micrographs of cross-sections of whole barley kernel CDC Legacy pearled to different levels.

PL0 PL1



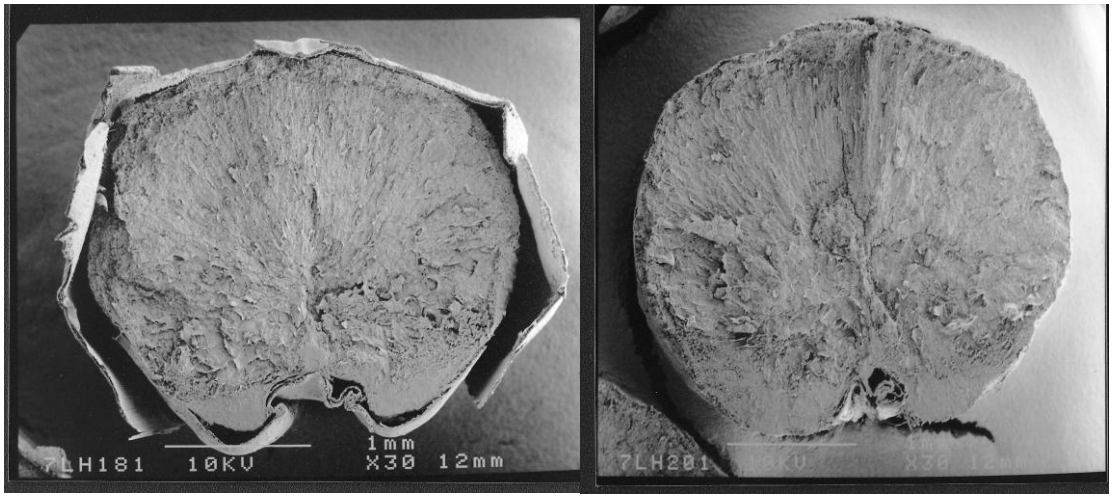
PL2 PL3



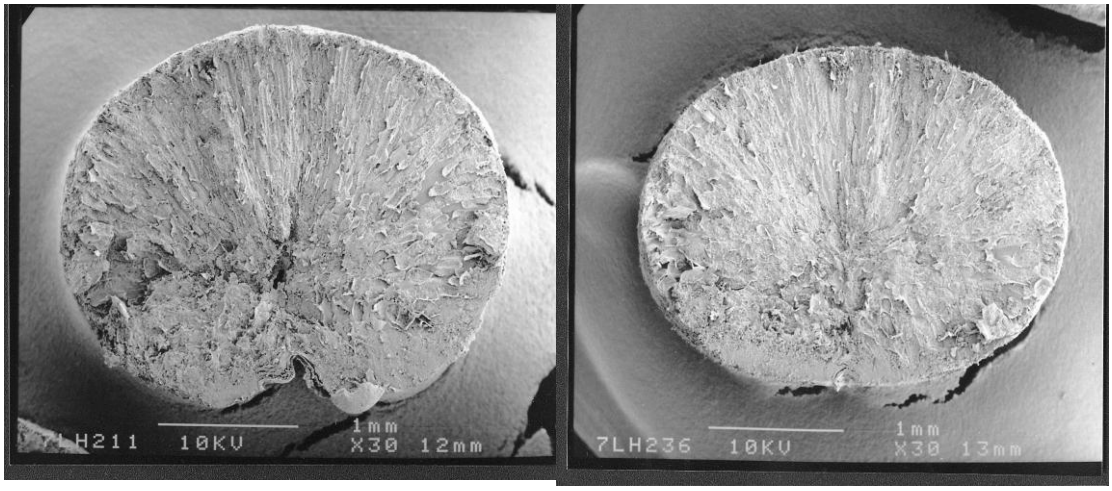
Level of outer layers removed; PL0- unpearled, PL1- 10%, PL2- 15%, PL3-30%

Figure 4.2. Scanning electron micrographs of cross-sections of whole barley kernel AC Metcalfe pearled to different levels.

PL0 PL1



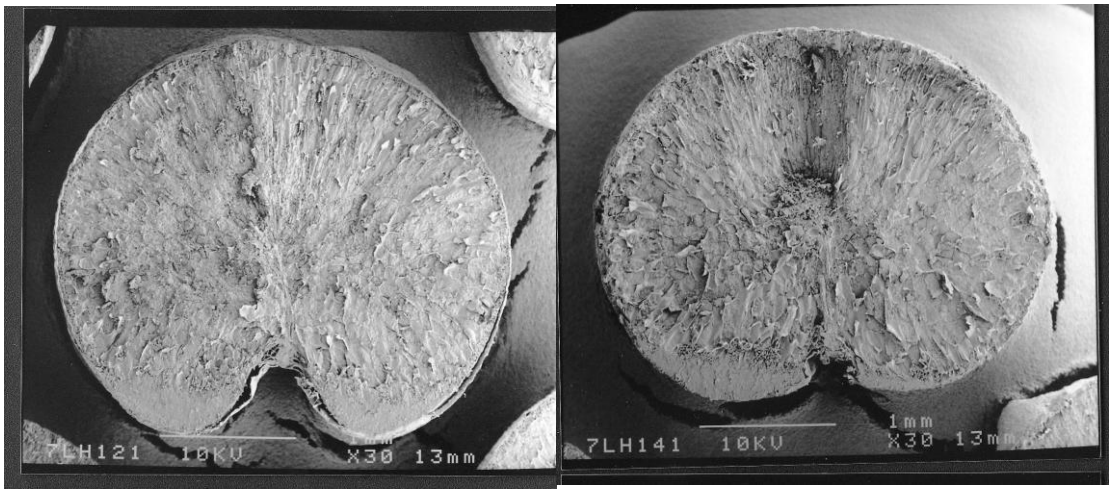
PL2 PL3



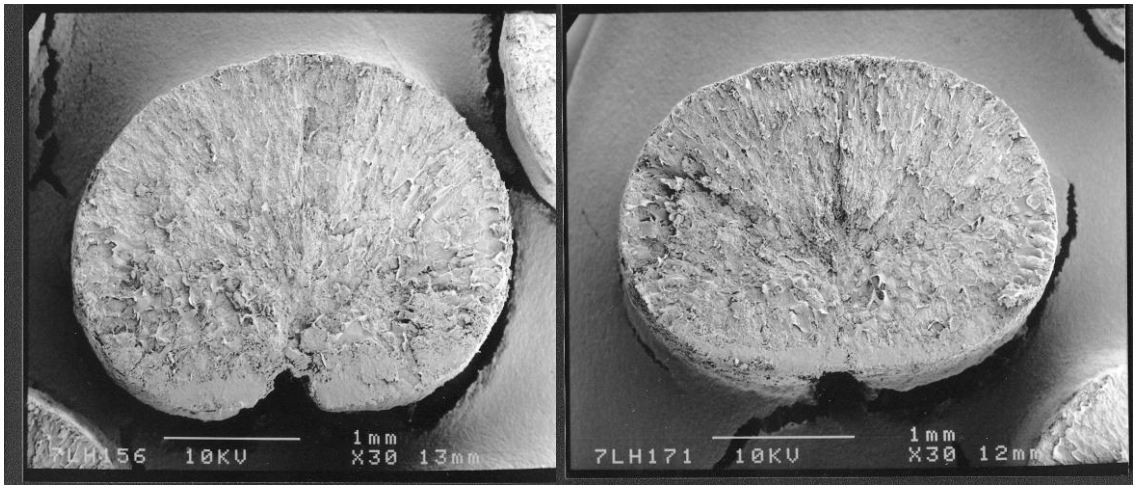
Level of outer layers removed; PL0- unpearled, PL1- 10%, PL2- 15%, PL3-30%

Figure 4.3. Scanning electron micrographs of cross-sections of whole barley kernel CDC McGwire pearled to different levels.

PL0 PL1



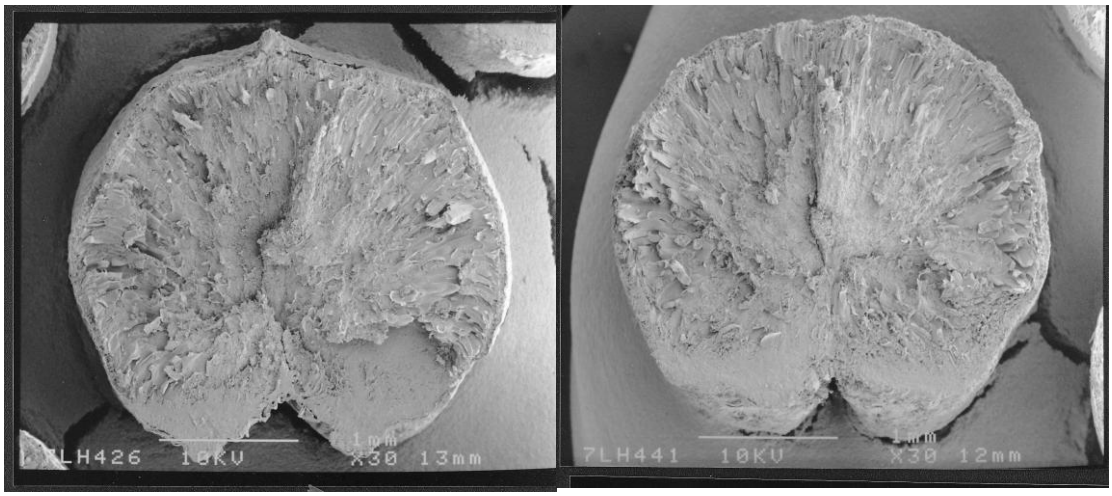
PL2 PL3



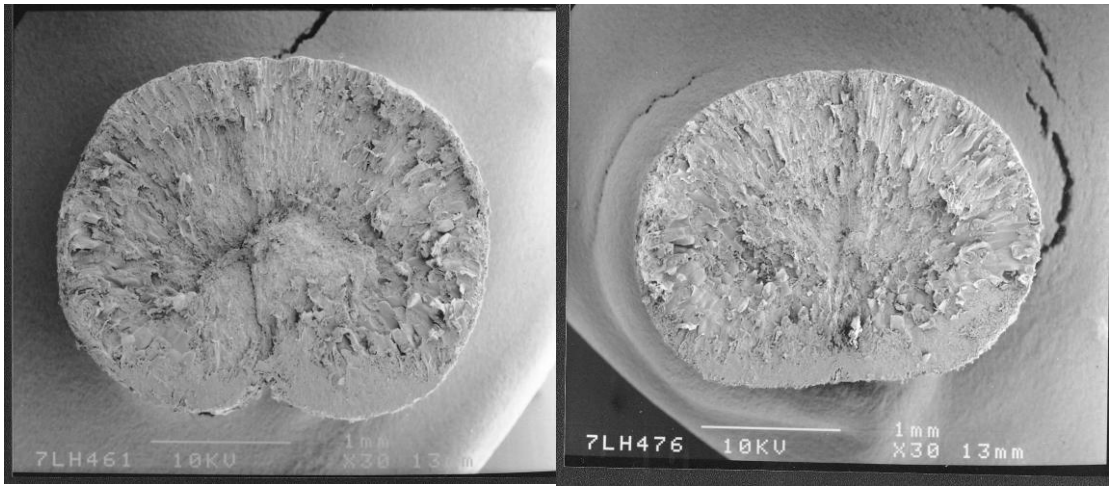
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

Figure. 4.4. Scanning electron micrographs of cross-sections of whole barley kernel CDC Alamo pearled to different levels.

PL0 PL1



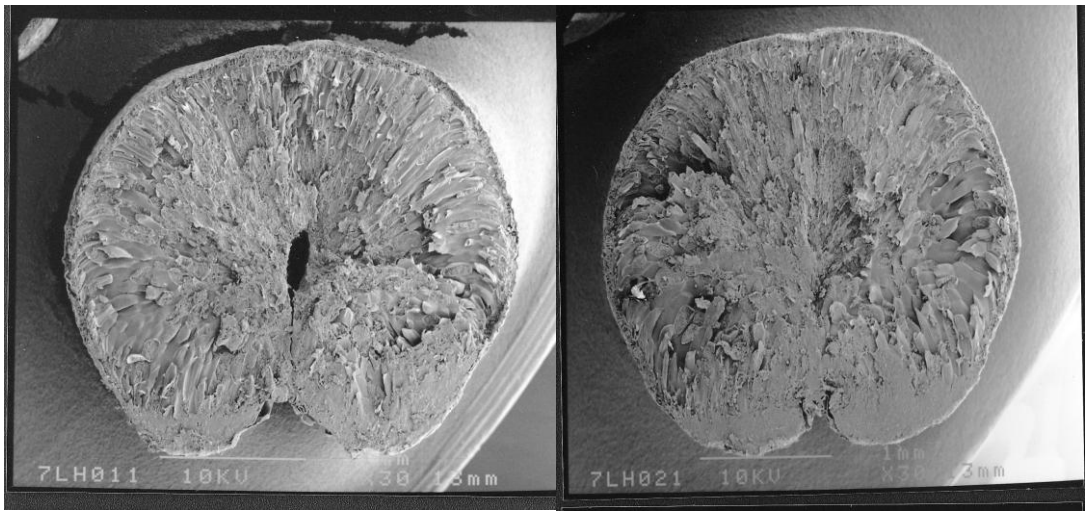
PL2 PL3



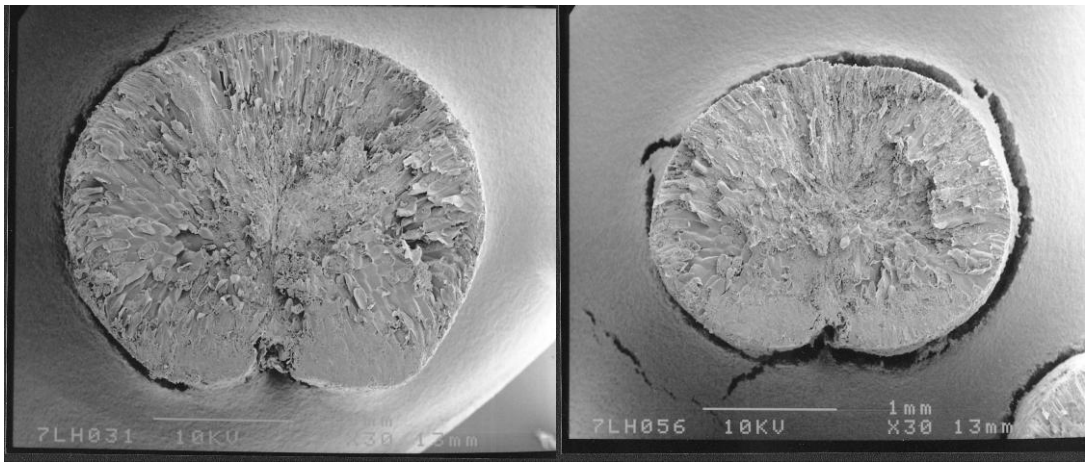
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

Figure 4.5. Scanning electron micrographs of cross-sections of whole barley kernel CDC Fibar pearled to different levels.

PL0 PL1



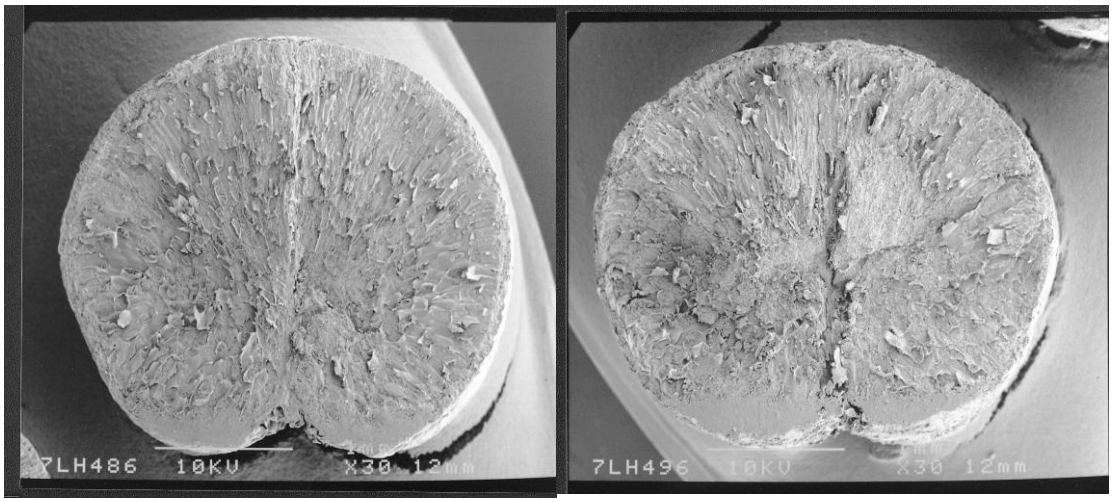
PL2 PL3



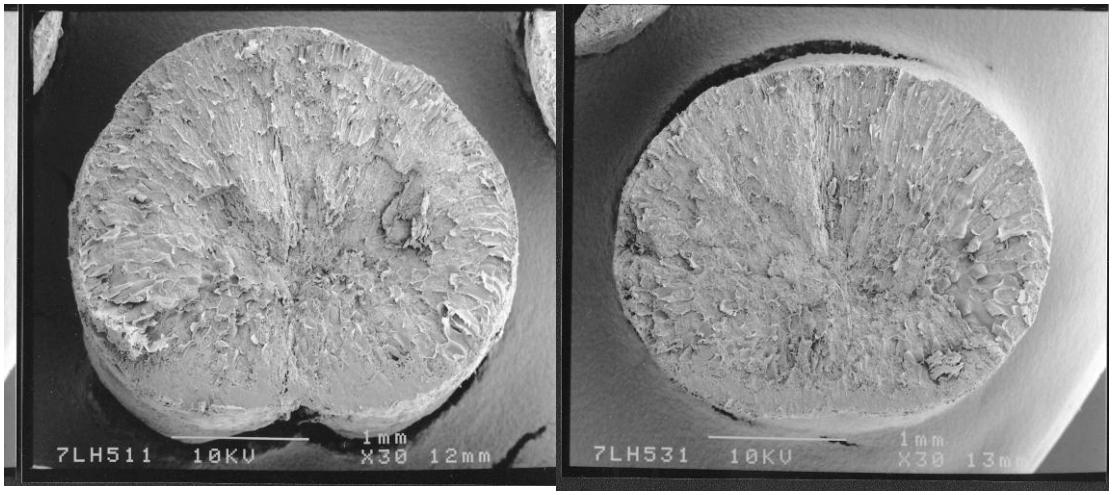
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

Figure 4.6. Scanning electron micrographs of cross-sections of whole barley kernel Enduro pearled to different levels.

PL0 PL1



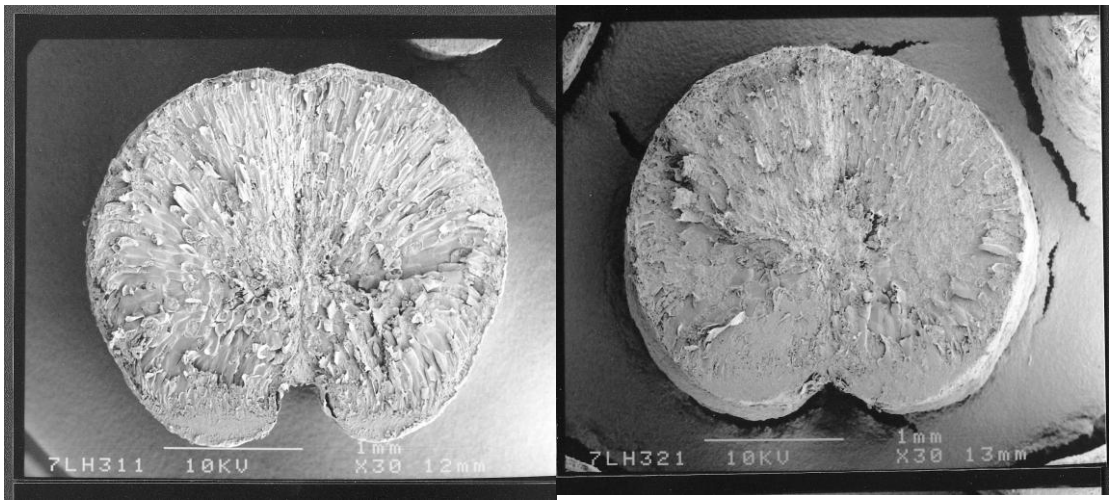
PL2 PL3



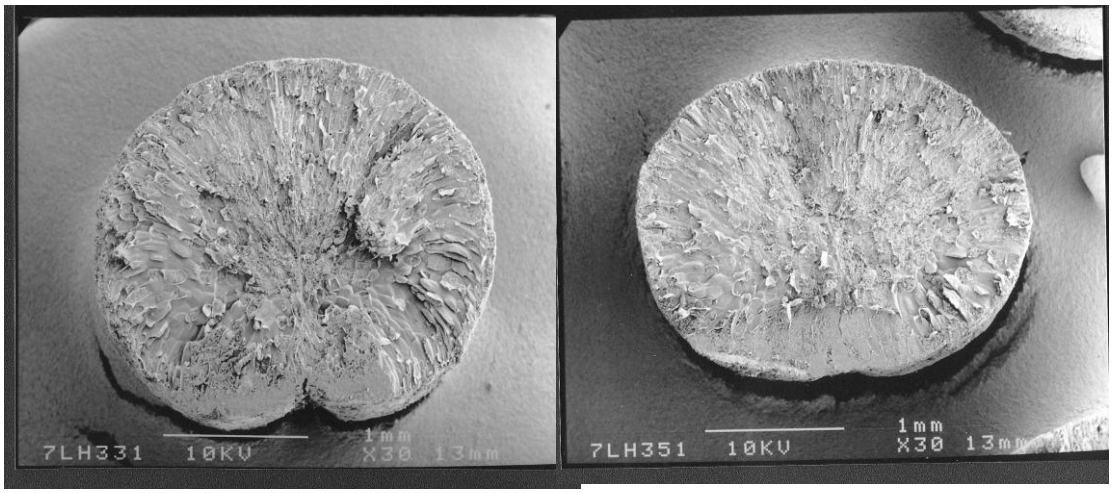
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

Figure 4.7. Scanning electron micrographs of cross-sections of whole barley kernel CDC Rattan pearled to different levels.

PL0 PL1



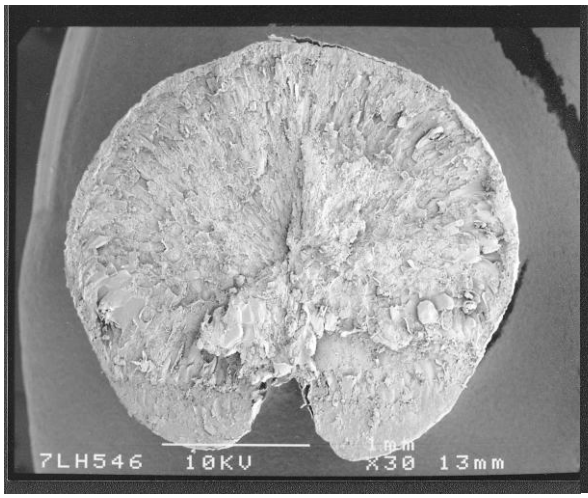
PL2 PL3



Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

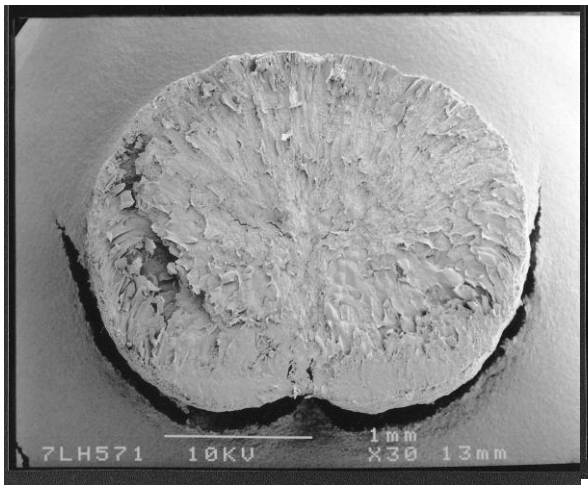
Figure 4.8. Scanning electron micrographs of cross-sections of whole barley kernel CDC SH99250 pearled to different levels.

PL0

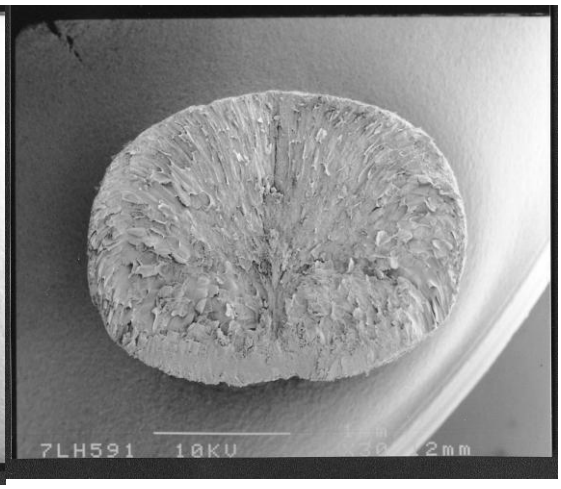


PL1

PL2



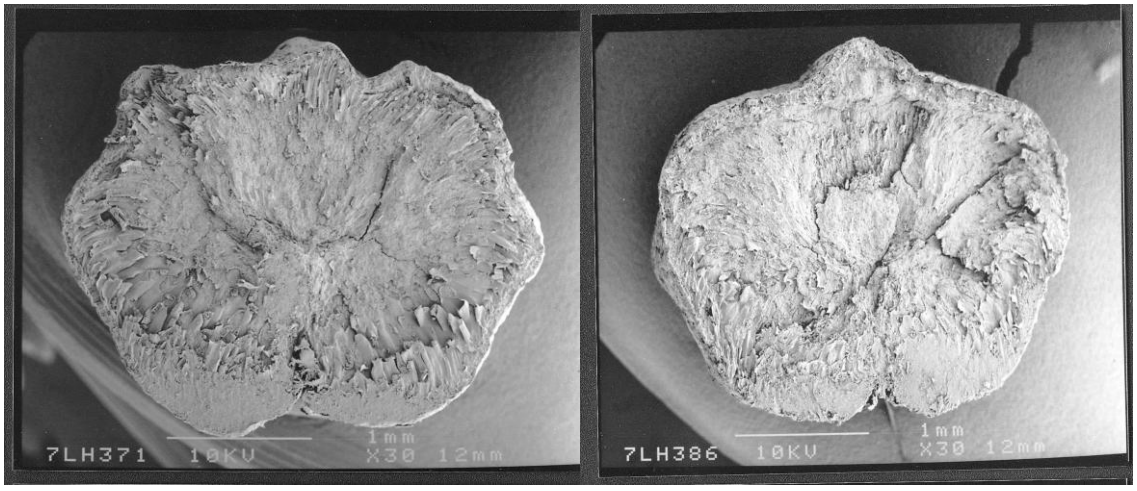
PL3



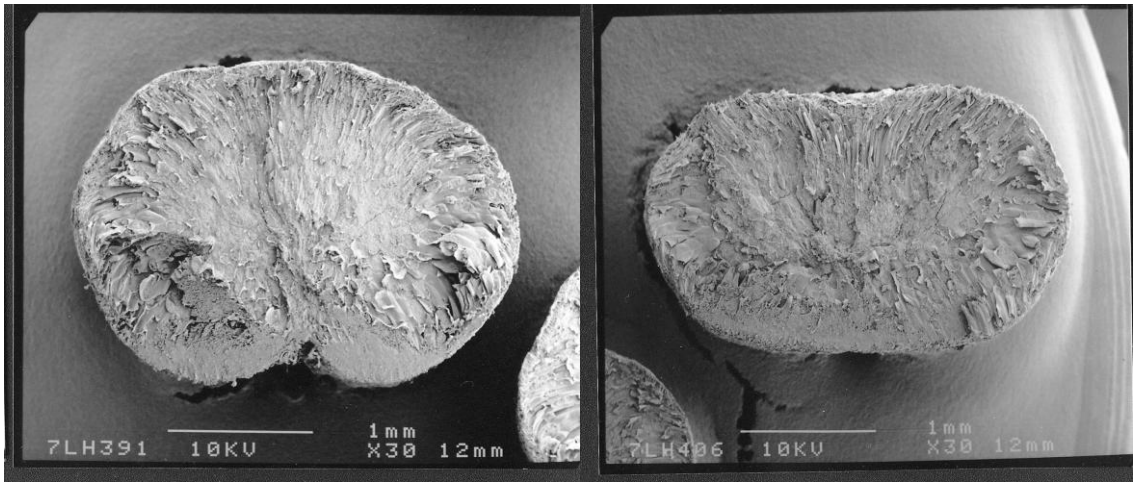
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

Figure 4.9. Scanning electron micrographs of cross-sections of whole barley kernel CDC SB94893 pearled to different levels.

PL0 PL1



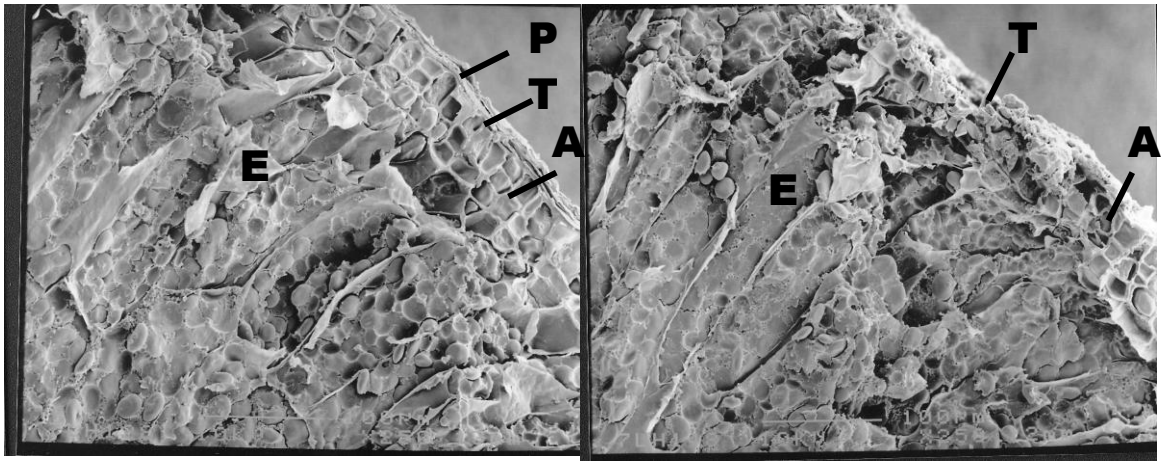
PL2 PL3



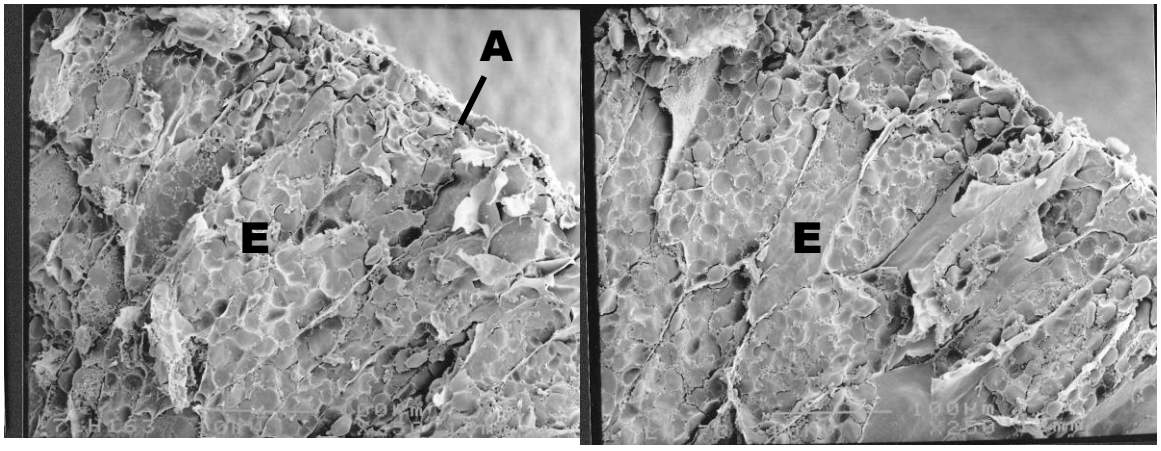
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

Figure 4.10. Scanning electron micrographs of cross-sections of CDC McGwire pearled to different levels.

PL0 PL1



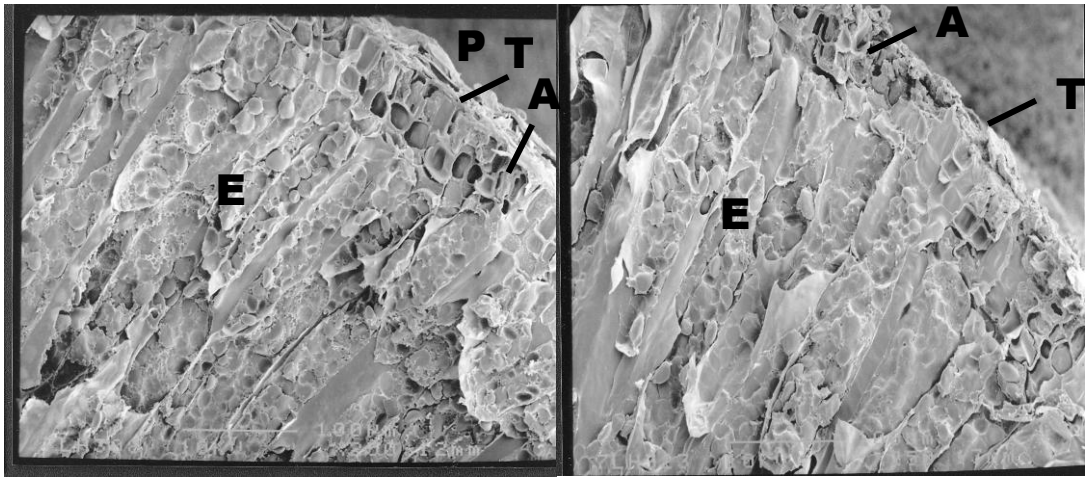
PL2 PL3



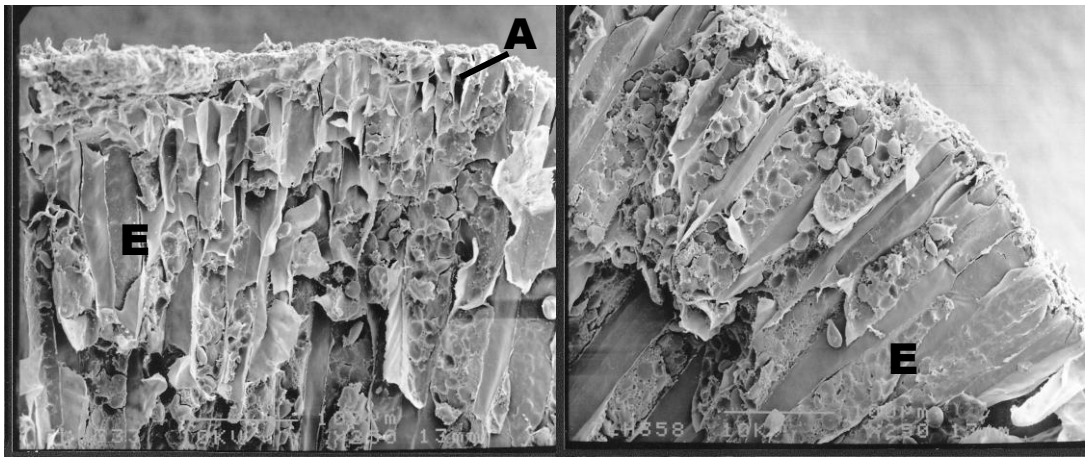
P – pericarp, T – testa, A – aleurone/subaleurone, E – starchy endosperm
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

Figure 4.11. Scanning electron micrographs of cross-sections of CDC Rattan pearled to different levels.

PL0 PL1



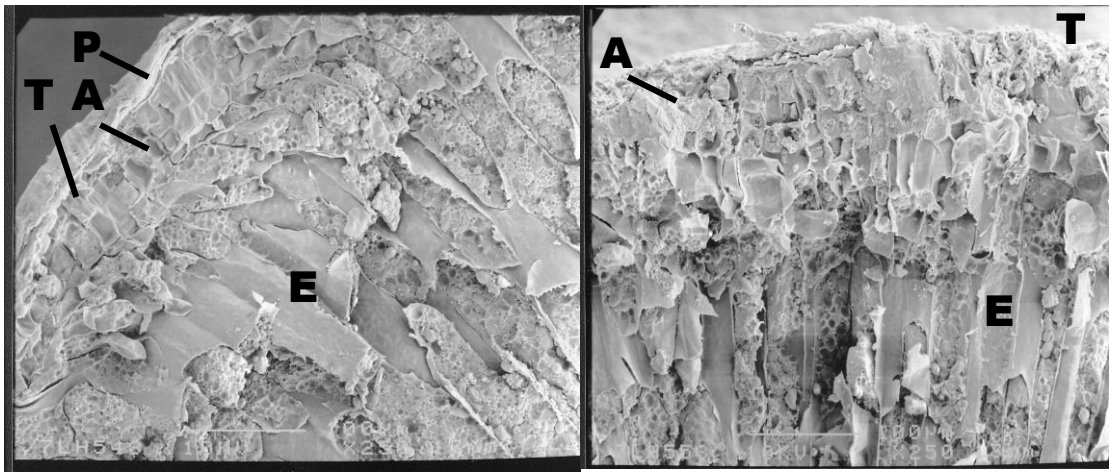
PL2 PL3



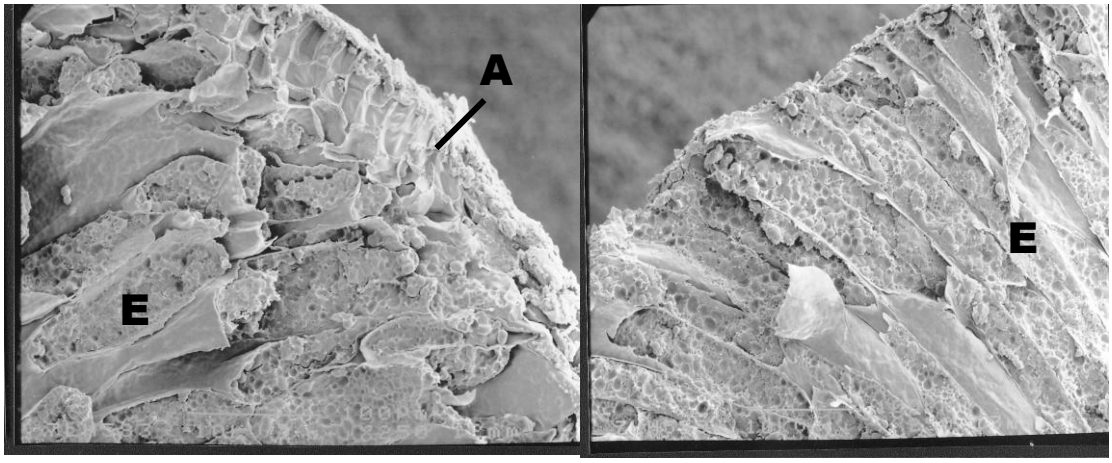
P – pericarp, T – testa, A – aleurone/subaleurone, E – starchy endosperm
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

Figure 4.12. Scanning electron micrographs of cross-sections of CDC SH99250 pearled to different levels.

PL0 PL1



PL2 PL3



P – pericarp, T – testa, A – aleurone/subaleurone, E – starchy endosperm
Level of outer layers removed; PL0- unpearled, PL1- 5%, PL2- 10%, PL3-25%

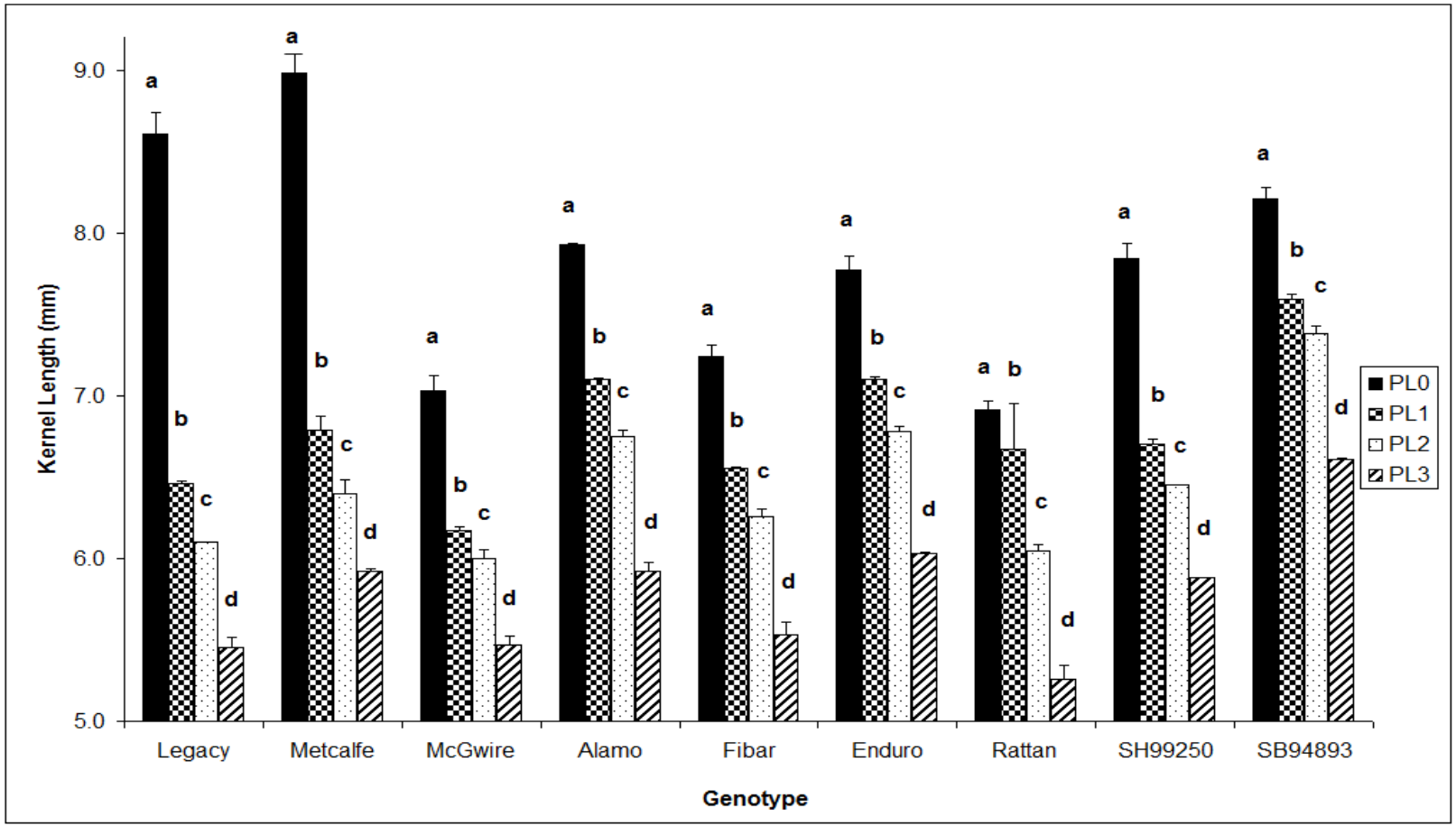
The non-uniform mode of size reduction of kernels during pearling was further confirmed by measuring the kernel dimensions of length, width, and height. For all

genotypes, the kernel length was significantly reduced at each PL (Figure 4.13). At the lowest rate of pearling (PL1), the HB genotypes had an average reduction of 10% kernel length compared to the original dimensions of unpearled kernels (PL0). However, the reduction varied substantially among genotypes, ranging from 3.4% for Rattan to 14.5% for SH99250. At the highest level of pearling (PL3), the average reduction of kernel length was approximately 24% with a small variation among genotypes (20 – 25%). Compared to HB, the average reduction of kernel length for the two hulled varieties (Legacy & Metcalfe) was much greater (average of 25% at PL1 and 36% at PL3) which was due to the higher abrasion rate that was applied to hulled barley at corresponding levels of pearling. The higher abrasion rate was applied to hulled barley to provide an even comparison between hulled and HB as the presence of hull caused the kernels to have a higher initial length.

Figure 4.14 shows the effect of genotype on kernel length of HB at each PL. At all levels of pearling, the HA starch genotype SB94893 was significantly longer than normal and waxy starch genotypes. The normal starch genotype McGwire and the waxy starch genotypes Fibar and Rattan were significantly shorter in length than other genotypes at all PL with the exception of the HA starch genotype SH99250 at PL1.

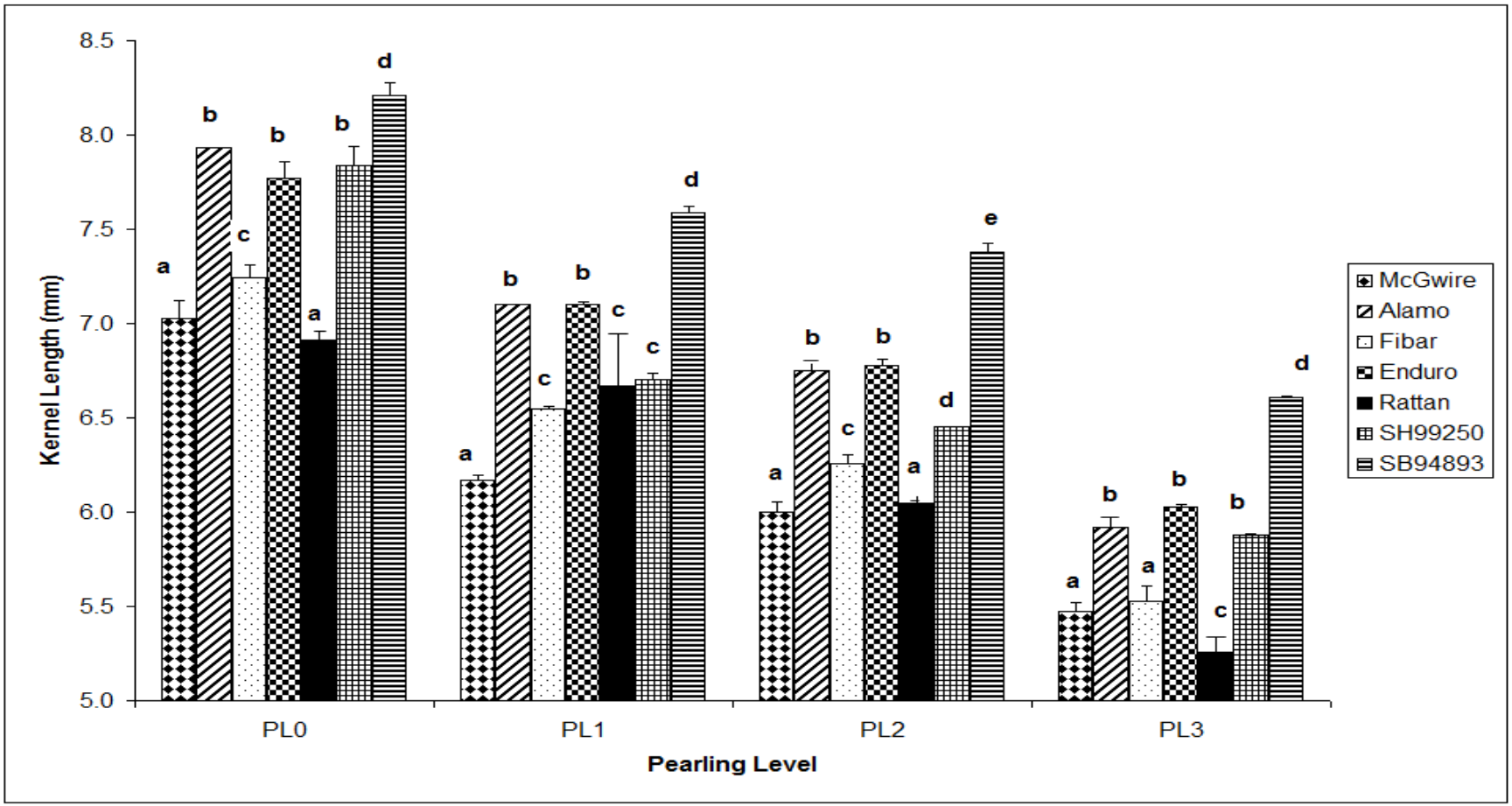
In general, the kernel width of HB was affected very little by pearling (Figure 4.15; Figure 4.3 – 4.9). The average reduction of kernel width for HB was 0% at PL1 and approximately 2.8% at PL3. The average reduction of kernel width for hulled barley at PL1 and PL3 was 6.5% and 10%, respectively. The effect of genotype on kernel width of

Figure 4.13. Effect of pearling level within each genotype on mean kernel length of selected Western Canadian barley varieties



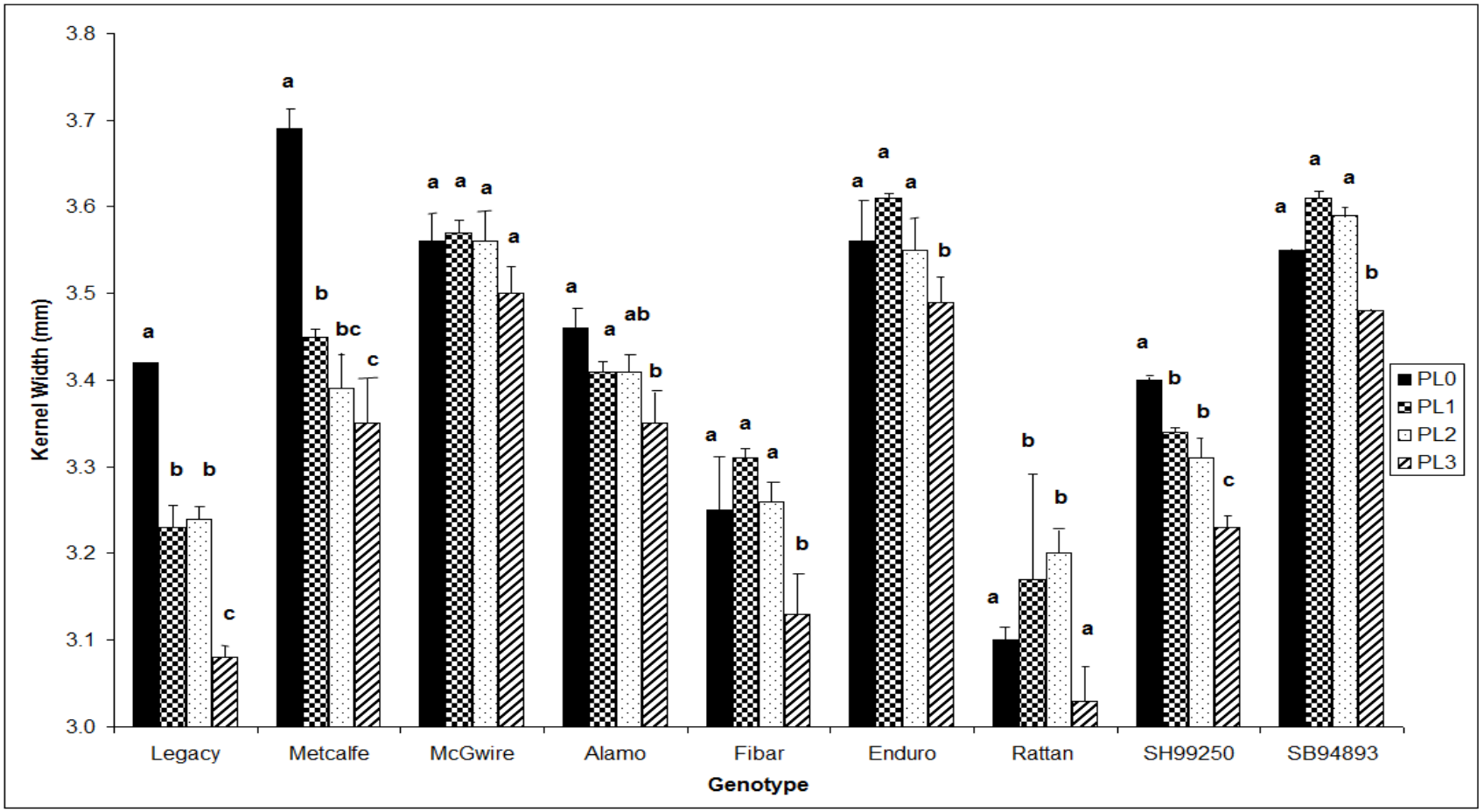
Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.14. Effect of genotype within each pearling level on mean kernel length of selected Western Canadian hulless barley varieties



Different letters (a, b, c, d) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

Figure 4.15. Effect of pearling level within each genotype on mean kernel width of selected Western Canadian barley varieties

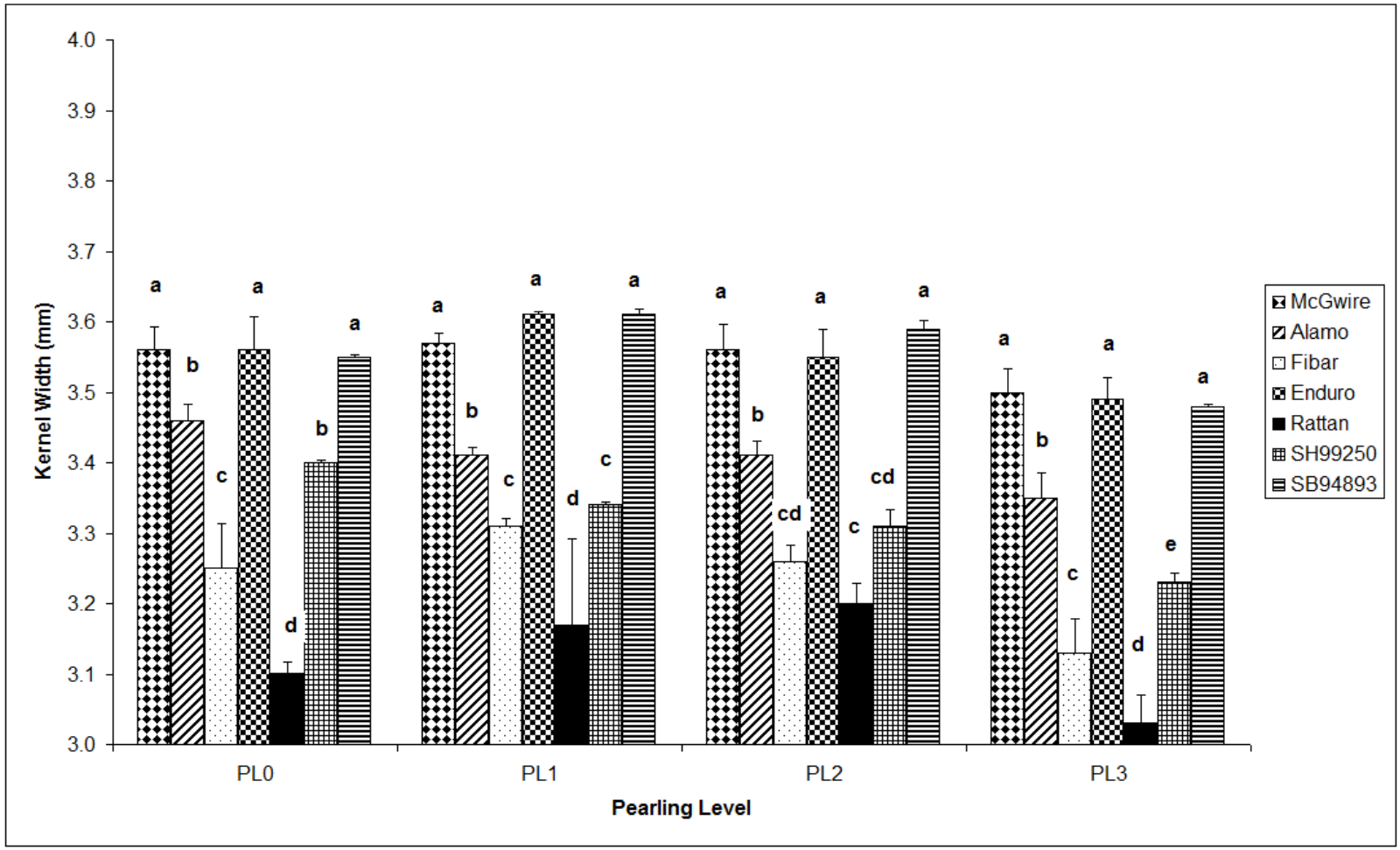


Different letters (a, b, c) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

the HB varieties at each PL is shown in Figure 4.16. At all PL, McGwire, Enduro, and SB94893 had significantly greater kernel width compared to other genotypes, whereas, the waxy starch genotype, Rattan, had the lowest kernel width. At PL1, PL2, and PL3, Fibar and SH99250 also had significantly lower kernel width values than all other genotypes except Rattan.

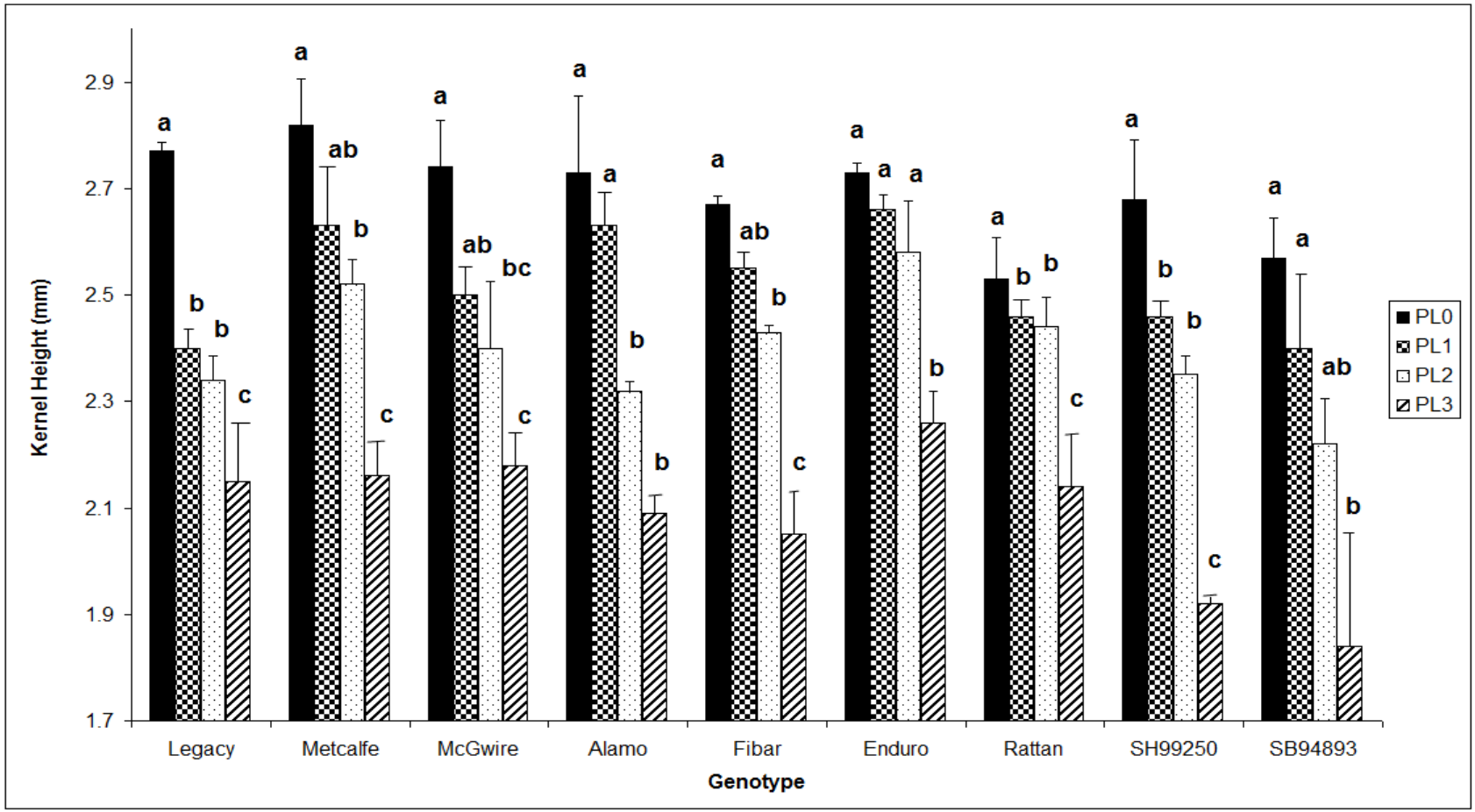
As shown in the SEM micrographs and Figure 4.17, the increasing degree of pearling had a substantial effect on kernel height. At PL1, kernel height was lower than it was for the unpearled kernels (PL0) but this reduction was only significant for Legacy, Rattan, and SH99250. However for all genotypes, there was a significant reduction of kernel height at PL3 compared to unpearled kernels (PL0). The average reduction of kernel height at PL1 for HB genotypes was 5.2% but large variations due to genotype were observed. At PL1, the lowest reduction of kernel height (2.5%) was for Enduro and Rattan while the highest (8.7%) was for McGwire. At PL3, the reduction in kernel height ranged from 15% for Rattan and Enduro to 28% for SH99250 and SB94893, with the average reduction of 22% for all HB genotypes. The average reduction in height of the hulled kernels at PL1 and PL3 was 10% and 23%, respectively. Figure 4.18 shows that there were no significant differences in kernel height among genotypes across PL, with the exception of Enduro, which had significantly greater height than SB94893 at PL1, PL2, and PL3.

Figure 4.16. Effect of genotype within each pearling level on mean kernel width of selected Western Canadian hulless barley varieties



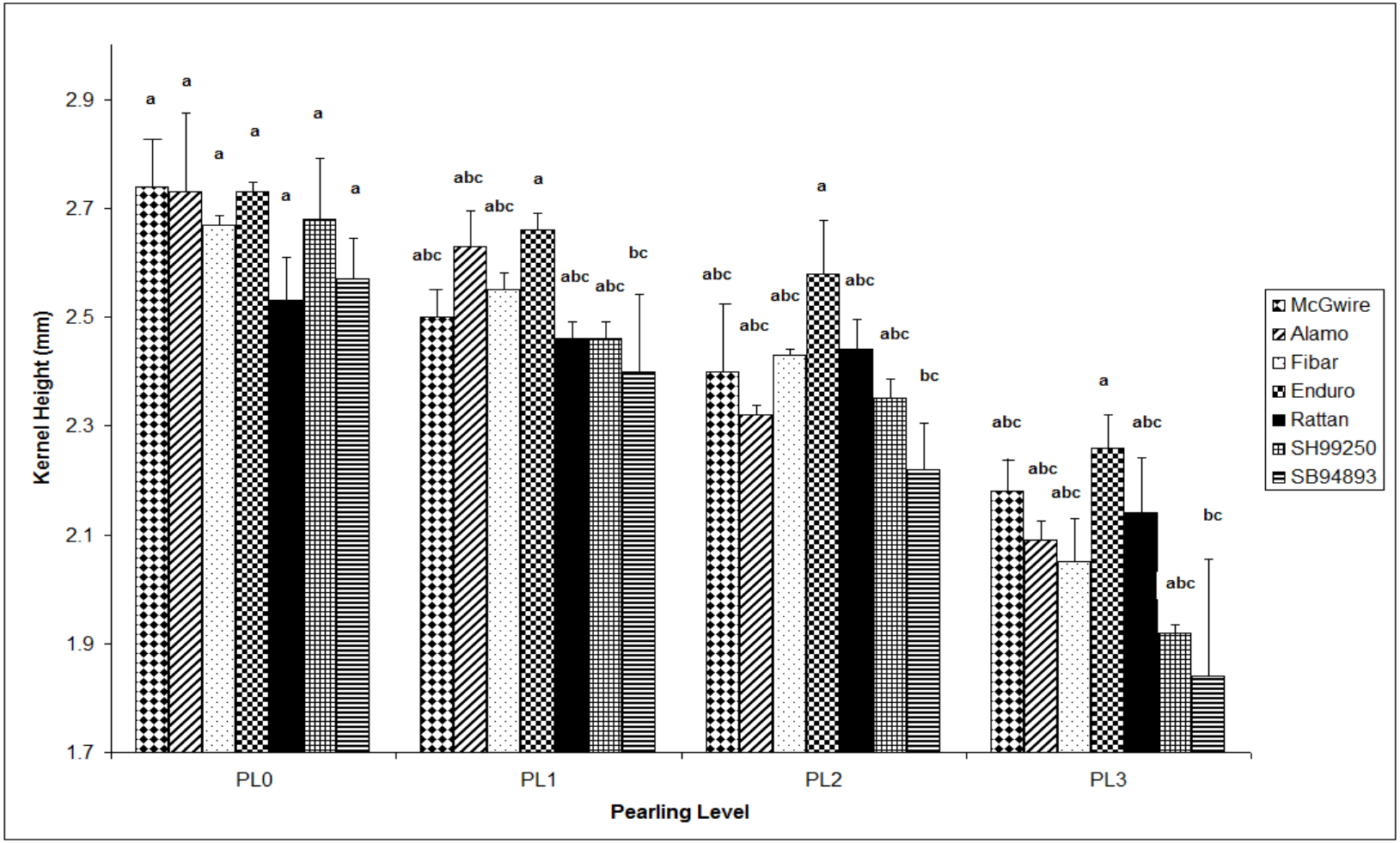
Different letters (a, b, c, d, e) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

Figure 4.17. Effect of pearling level within each genotype on mean kernel height of selected Western Canadian barley varieties



Different letters (a, b, c) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.18. Effect of genotype within each pearling level on mean kernel height of selected Western Canadian hulless barley varieties



Different letters (a, b, c) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

The results of this study clearly show that during pearling there is an uneven abrasive scouring of the outer layers of barley kernels. Generally, the major reduction in size occurred along the major axis of the kernel, affecting the length of kernels to the greatest extent. The width of kernel during pearling was affected to a relatively small extent. Some removal of the outer tissues happened also at the dorsal and ventral sides of kernel, causing considerable reduction in kernel height. As a result of pearling, the ellipsoidal shape of the barley kernel is transformed into a flattened sphere shape. This study has shown the extent of changes in size and shape of kernels during pearling is affected not only by the degree of abrasive scouring but also by the original kernel dimensions and properties.

4.1.1.2. Kernel hardness

When PL increased, differences in kernel hardness were observed for all barley genotypes studied but no consistent trends were observed. With the exception of Legacy, hardness increased for all genotypes when unpearled kernels (PL0) were compared to those at PL3 (Table 4.1) which suggests that the endosperm has a higher hardness index than the pericarp, testa, and aleurone layers.

Table 4.1. Mean[a] hardness index values for selected Western Canadian barley varieties as affected by genotype and pearling level

	Pearling Level[b]			
Sample	**PL0**	**PL1**	**PL2**	**PL3**
Legacy	**73.72** ± 17.15	**76.39** ± 16.98	**74.75** ± 16.20	**72.03** ± 17.75
Metcalfe	**61.43** ± 15.78	**60.20** ± 17.74	**60.18** ± 17.76	**62.92** ± 18.57
McGwire	**61.72** ± 15.40	**57.77** ± 16.41	**60.33** ± 17.06	**67.19** ± 17.90
Alamo	**52.94** ± 13.80	**57.33** ± 17.75	**58.03** ± 16.79	**55.37** ± 16.64
Fibar	**64.19** ± 14.99	**64.79** ± 17.07	**66.77** ± 16.45	**67.73** ± 17.01
Enduro	**57.17** ± 15.07	**62.17** ± 17.34	**63.03** ± 18.44	**60.51** ± 19.68
Rattan	**54.01** ± 15.30	**58.38** ± 18.15	**57.30** ± 16.42	**55.26** ± 16.58
SH99250	**90.44** ± 14.18	**93.81** ± 15.93	**95.54** ± 15.42	**102.23** ± 15.35
SB94893	**76.92** ± 13.19	**79.36** ± 14.66	**82.72** ± 14.96	**91.30** ± 17.55

[a] Mean: n=2 obtained from 300 values each
[b] Level of outer layer removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layer removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Starch characteristics within each HB genotype affected hardness values (Table 4.1). The HA starch genotypes SH99250 and SB94893 were noticeably harder than other HB genotypes which may be due to the larger percentage of amylose present in these lines. Edney (2002) reported that firmer barley kernels have better potential to resist damage during processing which would suggest that HA starch genotypes have a higher resistance to damage during pearling. At all levels of pearling, the waxy starch genotype Fibar was harder than the other waxy starch genotypes Alamo and Rattan which could be due to its higher β-glucan content. Gamlath et al. (2008) found a strong positive correlation ($r = 0.87$) between kernel hardness and β-glucan content. It was proposed that higher proportions of β-glucan and arabinoxylans result in thicker cell walls throughout the endosperm which results in a harder barley kernel. HA starch genotypes were also

noted for having high β-glucan content which may partially explain their increased hardness.

4.1.1.3. Pearling time and determination of broken kernels

The pearling time required to achieve desired levels of pearling varied depending on the PL and genotype examined. As expected as PL increased, there was an increase in time required to pearl (Table 4.2). Pearling time required for waxy starch genotype Rattan was longer than the time needed for other varieties. Edney et al. (2002) found that smaller barley kernels required longer pearling times due to more space within the pearler which resulted in less friction against the stone. As discussed previously, Rattan was found to be significantly smaller than other varieties which explains its longer pearling time. A longer length of time was also needed to pearl the HA starch genotype SH99250 which could be due to its smaller kernels and higher kernel hardness and level of amylose. Although, the other HA starch genotype SB94893 did not require a long pearling time which could be explained by its larger kernel size.

Table 4.2. Range of time required to pearl selected Western Canadian barley varieties to designated levels as affected by genotype and pearling level[a]

	Pearling Time (s)		
	PL 1	**PL 2**	**PL 3**
Legacy	20 – 25	50	170 – 180
Metcalfe	16 – 20	45	140 - 145
McGwire	24 – 26	60	155 – 160
Alamo	18 – 20	42 – 44	150 - 160
Fibar	20 – 22	46 – 50	175 – 190
Enduro	11 – 15	35 – 40	145 – 160
Rattan	25 – 30	65 – 67	200 – 215
SH99250	25 – 27	64	200 – 210
SB94893	18	40	130 - 145

[a] Level of outer layer removed for HB samples; PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layer removed for hulled barley samples; PL1- 10%, PL2- 15%, PL3- 30%

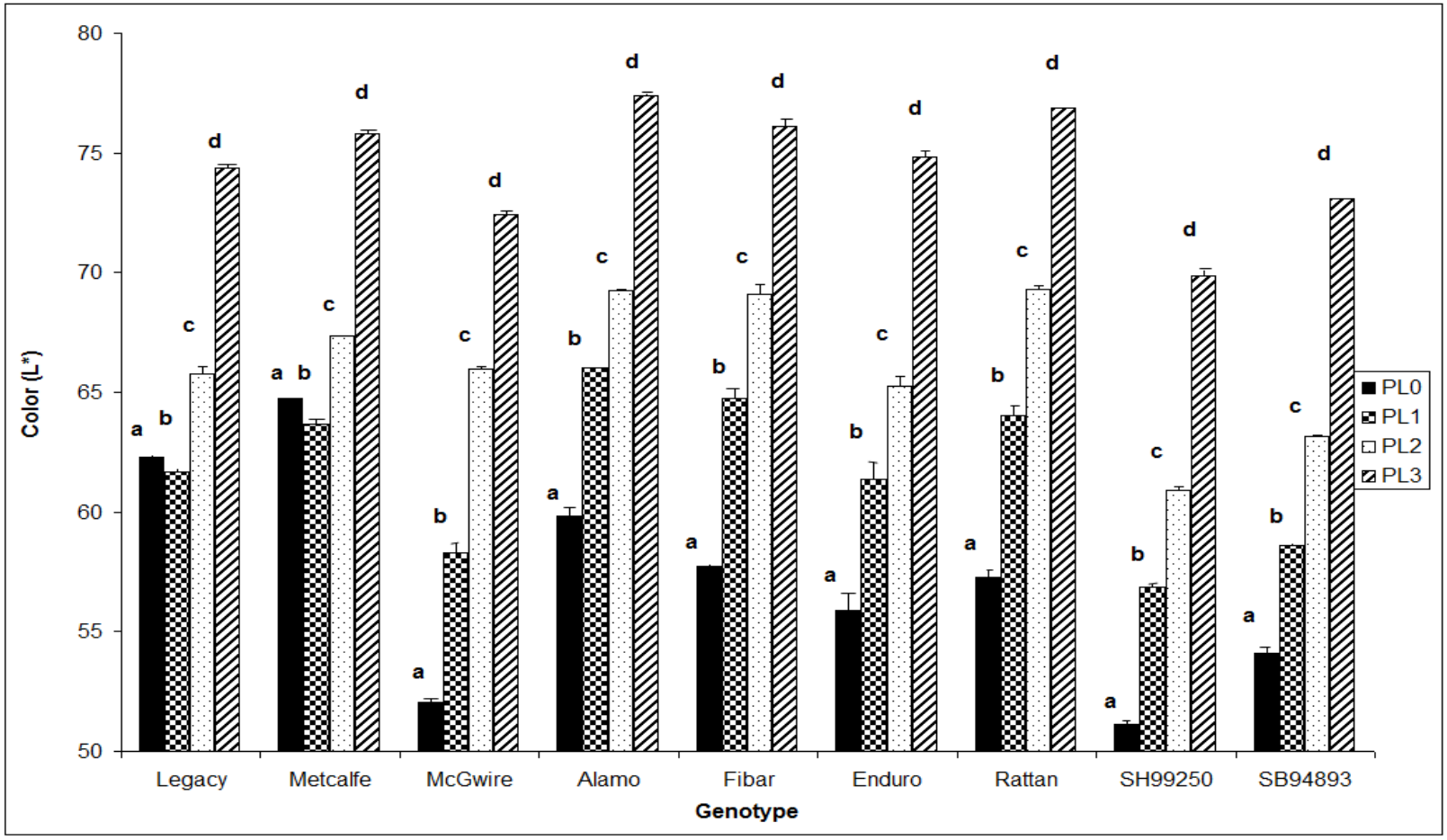
Whole, unbroken barley kernels are desired after pearling. As PL increased, there was a corresponding increase in broken kernels suggesting that once the protective outer layer is removed there is an increased tendency for kernels to break (Appendix E). For hulled barley, the percentage of broken kernels was larger (average 11.9%) compared to HB (average 3.9%) when unpearled samples were compared to those subjected to PL3. No consistent trend in percent of broken kernels was observed among HB varieties with differing starch characteristics. In contrast, Edney et al. (2002) reported that when 40% of the outer layer was removed, waxy starch genotypes had a significantly lower percentage of broken kernels compared to normal starch HB.

4.1.1.4. Instrumental determination of brightness of uncooked barley kernels

Ideally, barley kernels should have a bright appearance. Figure 4.19 shows that for every increase in level of pearling, brightness significantly increased with the exception of hulled genotypes, where unpearled samples (PL0) were significantly brighter than those at PL1 due to the presence of the light colored hull. Once the outer layer was removed from HB genotypes, their brightness significantly increased suggesting that the endosperm is brighter than the pericarp, testa, and aleurone layers.

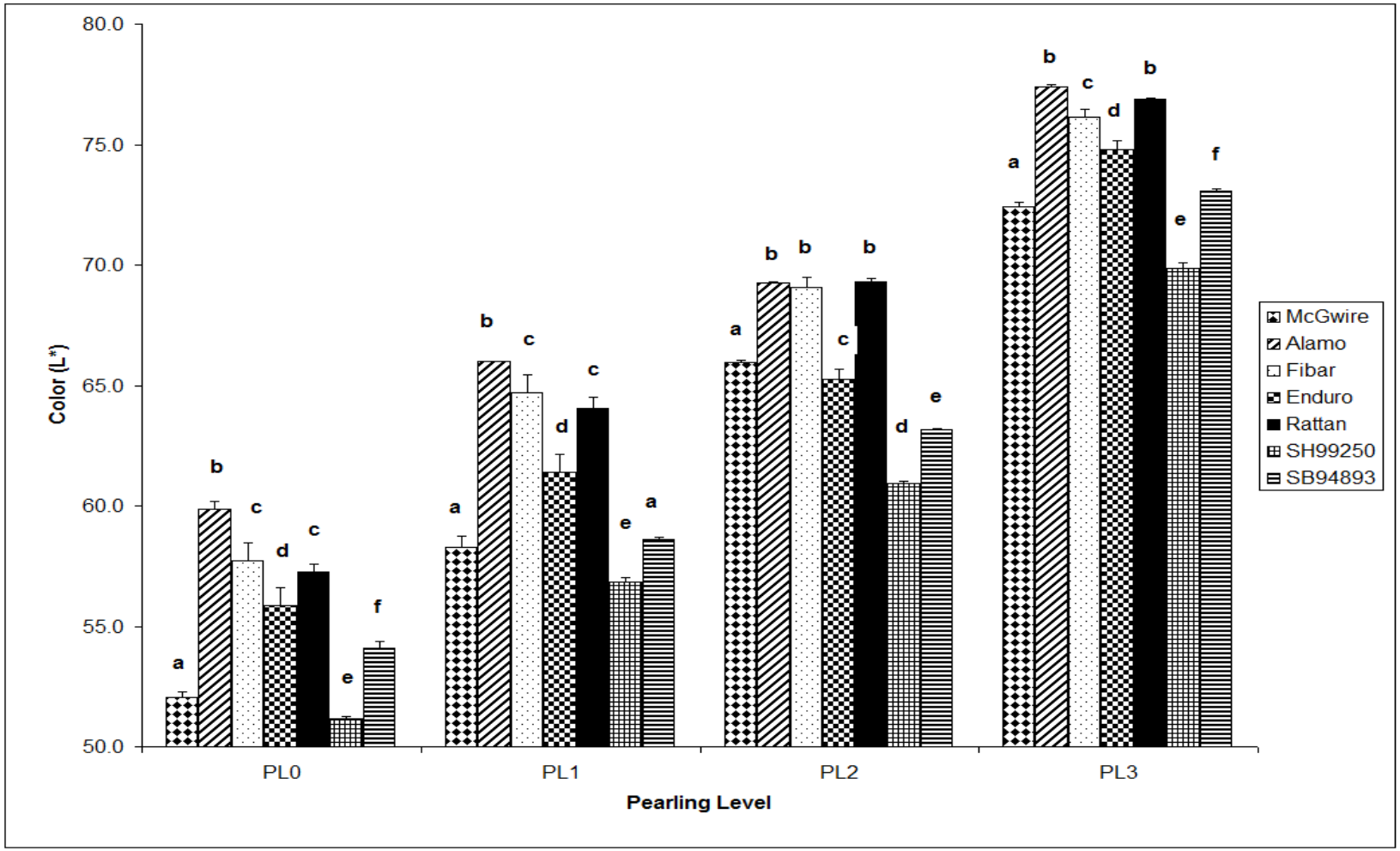
Significantly lower brightness was observed for normal and HA starch genotypes compared to waxy starch genotypes (Figure 4.20). Across all PL, the HA starch genotype SH99250 was significantly less bright than other genotypes, which was also confirmed visually. Box et al. (2007) found that at a 20% level of pearling, the waxy starch HB had significantly higher brightness values than normal and HA starch genotypes and this was also found in the present study with the exception of the dark colored waxy starch genotype Enduro.

Figure 4.19. Effect of pearling level within genotype on mean brightness of selected Western Canadian barley varieties



Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.20. Effect of genotype within each pearling level on mean brightness of selected Western Canadian hulless barley varieties



Different letters (a, b, c, d, e, f) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

4.1.2. Composition

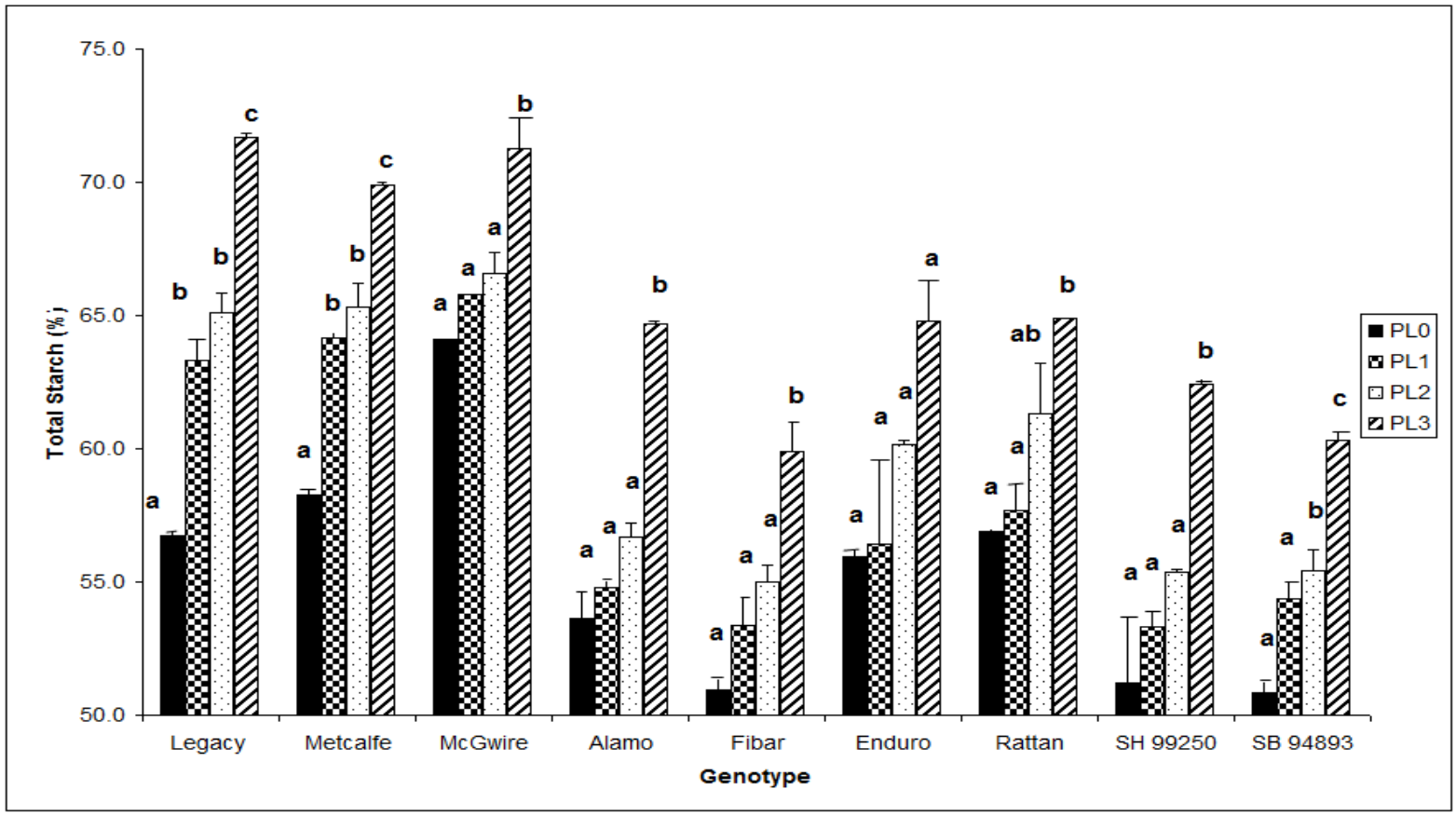
Whole grain barley contains an abundance of nutritional components which play an important role in improving human health. The level of pearling that should be applied to the barley kernel to retain the highest level of nutrients is critical knowledge for the processor. The effect of PL, genotype and their interaction significantly affected the proportion of starch, protein, ash, β-glucan, arabinoxylans, and free phenolic acids present. Appendix C shows that for all compositional properties examined, genotype, PL, and their interaction were significantly affected. Appendix D shows where significant differences exist between both genotype and PL for composition.

4.1.2.1. Total starch

For all genotypes except Enduro and Rattan, there was a significant increase in total starch concentration at PL3 compared to PL1 and PL2 (Figure 4.21). Klamczynski et al. (1998) and Bhatty & Rossnagel (1998) also showed that starch concentration increased with higher pearling levels. For hulled genotypes (Legacy and Metcalfe), there was a significant increase in starch concentration at PL1 compared to PL0 due to the removal of the hull.

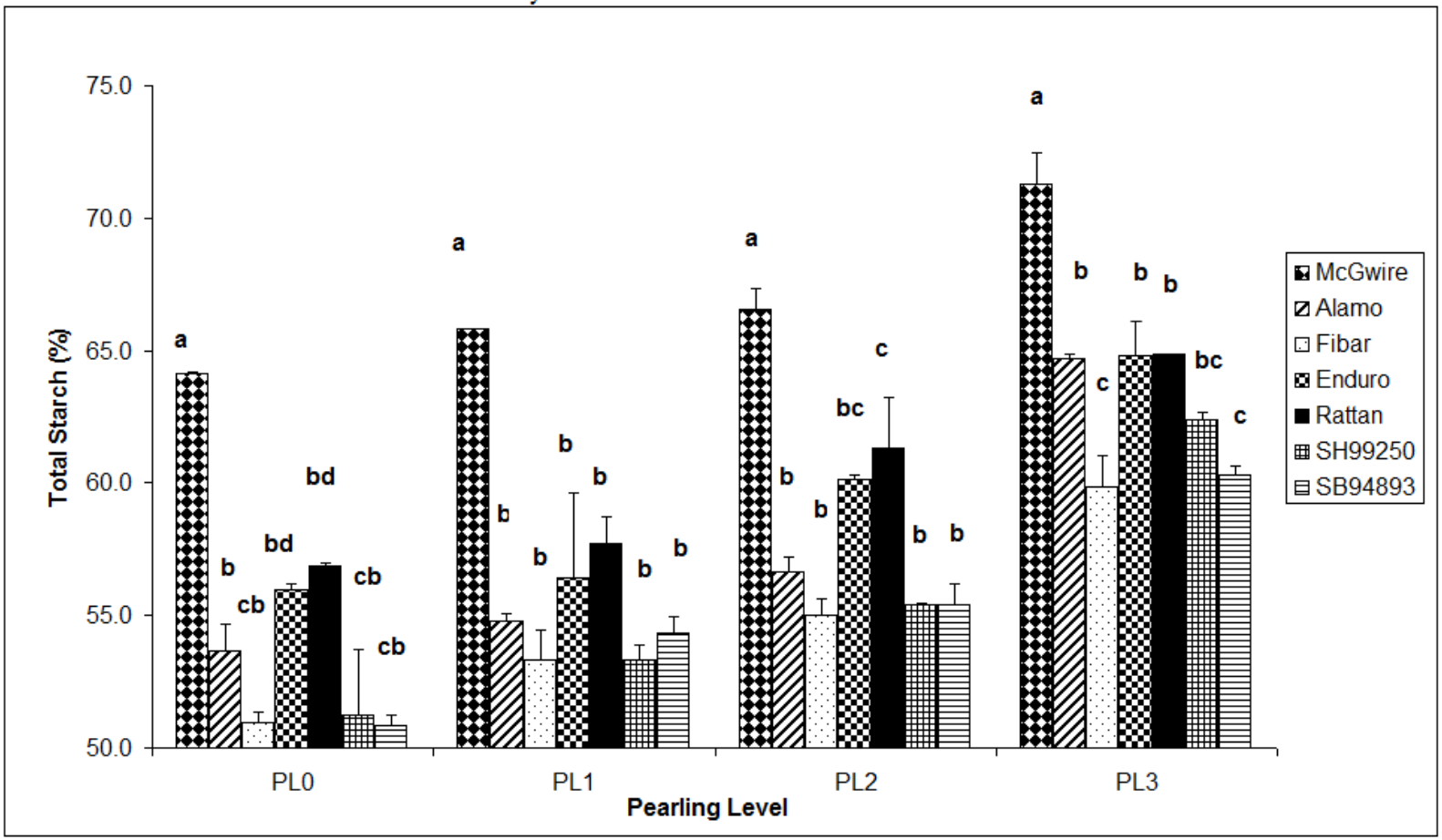
Total starch concentration of HB varieties was significantly affected by genotype (Figure 4.22). At all levels of pearling, the normal starch barley variety McGwire had a significantly higher level of starch compared to modified starch genotypes which agrees with findings of Yeung and Vasanthan (2001). At PL1, there were no significant differences found among the modified starch genotypes. At PL2, Rattan had significantly higher total starch levels than all modified starch genotypes with the exception of Enduro. At PL3, the waxy starch genotype Fibar had a significantly lower level of starch

Figure 4.21. Effect of pearling level within each genotype on mean total starch concentration (dry weight basis) of selected Western Canadian barley varieties



Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.22. Effect of genotype within each pearling level on mean total starch concentration (dry weight basis) of selected Western Canadian hulless barley varieties



Different letters (a, b, c, d) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

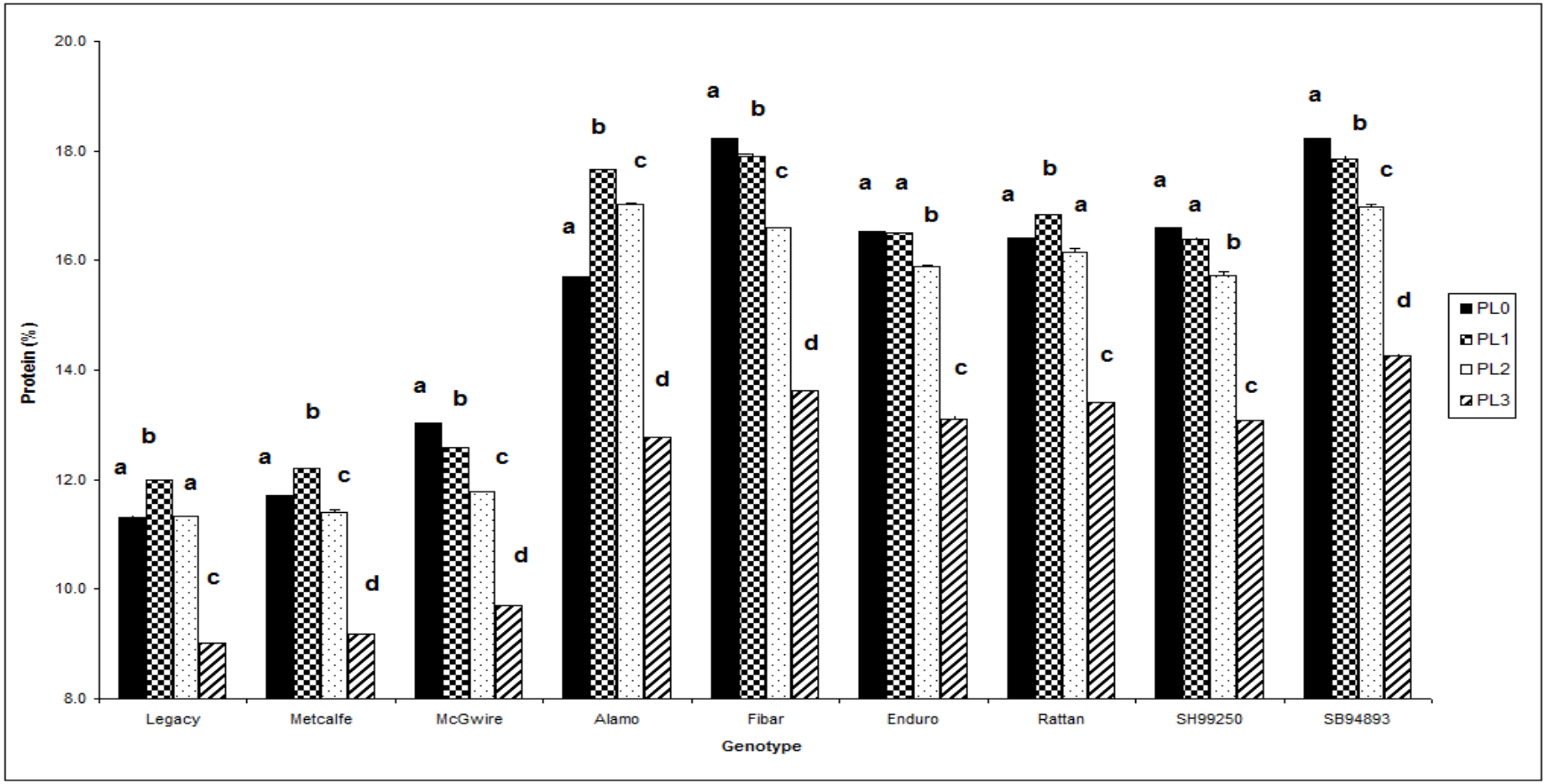
compared to the other waxy starch genotypes (Alamo, Enduro, and Rattan) which may be due to its higher level of β-glucan. At PL3, similar to Fibar, the HA starch genotype SB94893 contained significantly lower levels of starch compared to other genotypes which could also be attributed to its high β-glucan level.

4.1.2.2. Protein

As pearling increased, there was a significant decrease in protein concentration across all genotypes (Figure 4.23). The lowest protein levels were found at PL3 for all genotypes which is consistent with the higher levels of starch found at PL3. From the SEM micrographs, it was observed that the aleurone layer is removed at PL3. A significant decrease in protein content was observed at PL3 for all genotypes which is expected as the aleurone layer contains approximately 2-3% of the protein present in the kernel. Hulled genotypes, Legacy and Metcalfe, had lower protein content than HB genotypes which is in agreement with results published by other researchers (Edney et al. 2002; Oscarsson et al. 1996; Pomeranz et al. 1976). The significantly lower level of protein found in unpearled (PL0) hulled barley genotypes compared to protein levels at PL1 was due to the presence of hull.

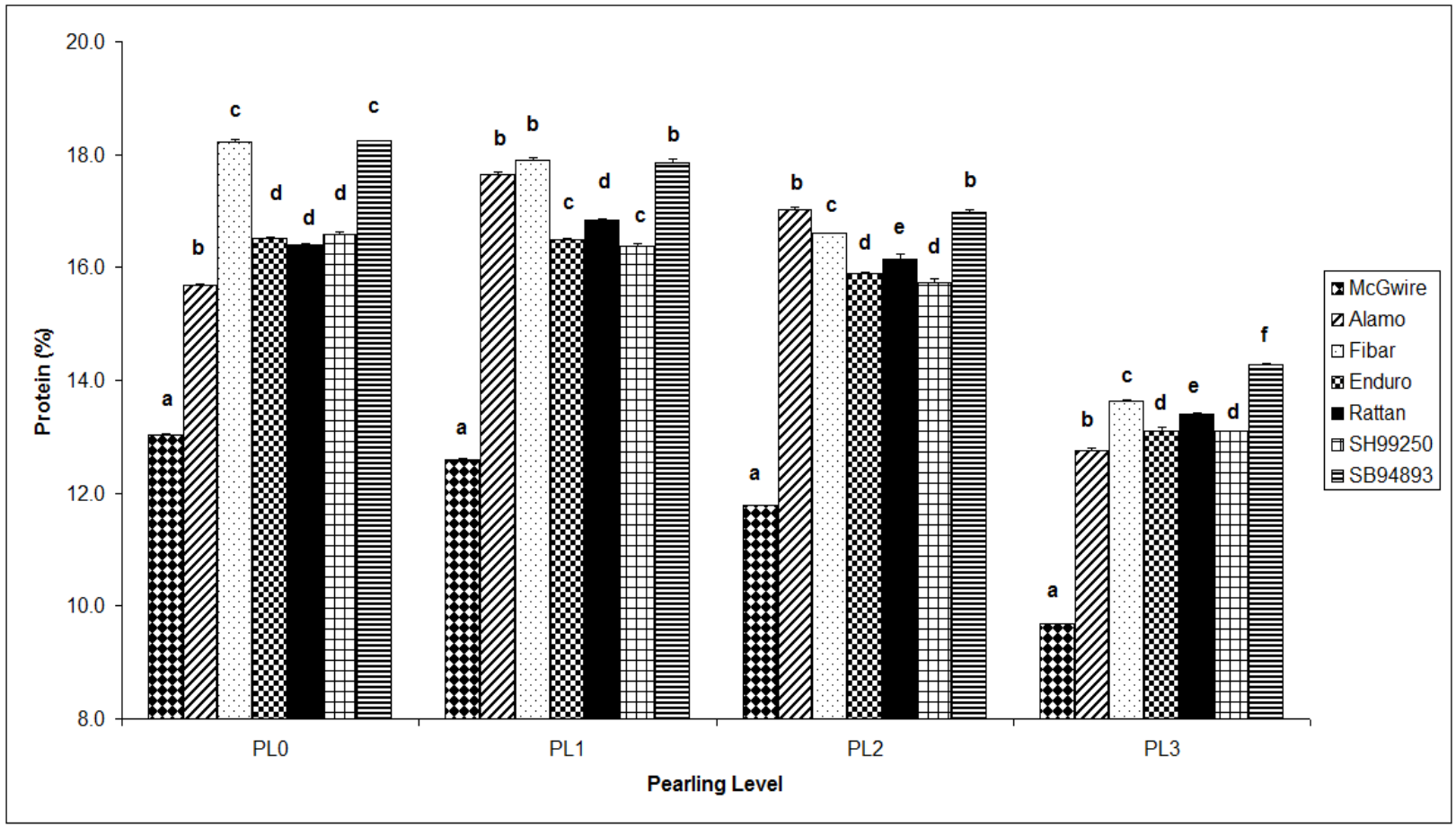
Significant differences in protein content were observed among HB genotypes (Figure 4.24). At all pearling levels, the normal starch genotype McGwire had significantly lower protein levels compared to modified starch genotypes. Edney et al. (2002) found that unpearled normal starch genotype McGwire had a significantly lower concentration of protein than unpearled waxy starch genotypes. At PL3, there were significant differences in protein content among all genotypes with the exception of the waxy starch genotype Enduro and the HA starch genotype SH99250. The HA genotype

Figure 4.23. Effect of pearling level within genotype on mean protein concentration (dry weight basis) of selected Western Canadian barley varieties



Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.24. Effect of genotype within pearling level on mean total protein concentration (dry weight basis) of selected Western Canadian hulless barley varieties



Different letters (a, b, c, d, e, f) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

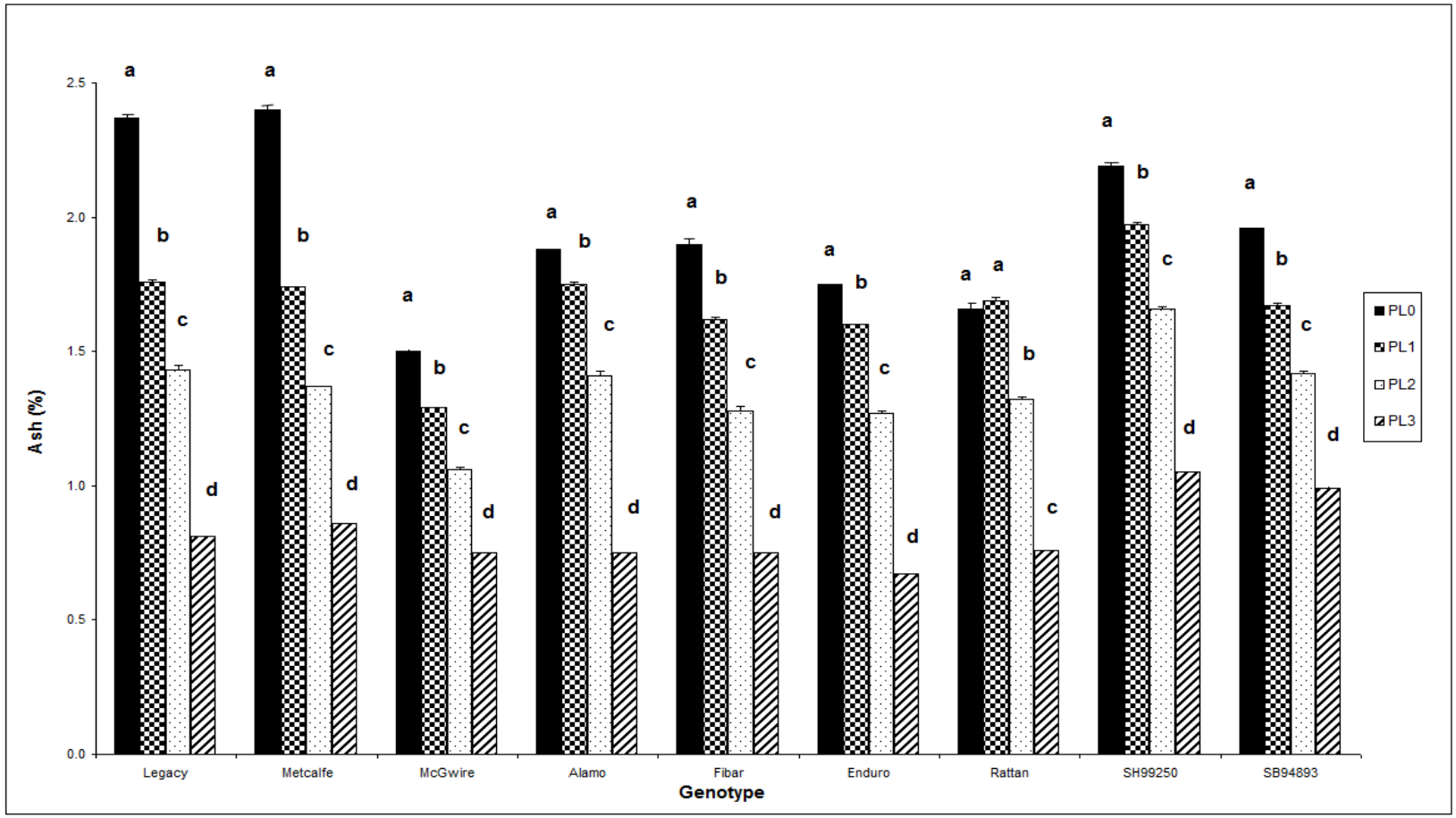
SB94893 had the highest concentration of protein, whereas the waxy genotype Alamo had the lowest protein concentration of all the modified starch genotypes.

4.1.2.3. Ash

As shown in Figure 4.25, the ash concentration significantly decreased as PL increased across all genotypes with the exception of waxy starch genotype, Rattan which contained similar levels of ash at PL0 & PL1. There was a large reduction in ash concentration in all genotypes processed to PL3 compared to their unpearled form (average of 49%). The decrease in ash concentration at higher PL is in agreement with results of previous research (Yeung & Vasanthan 2001; Hashimoto et al. 1987).

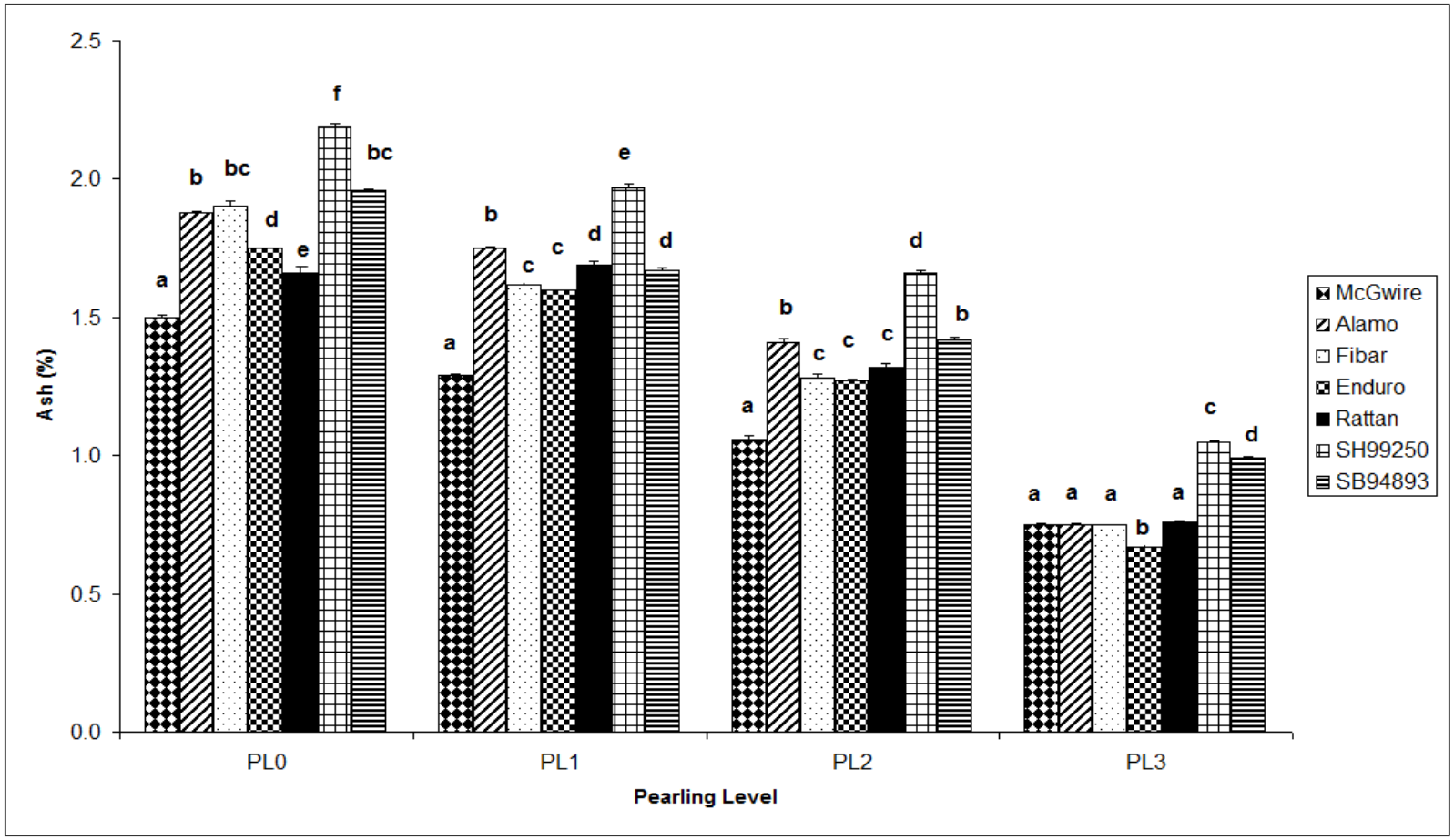
As expected, the unpearled hulled genotypes Legacy and Metcalfe had higher ash levels than HB genotypes due to the presence of hull. Other studies also found that the presence of the hull on the barley kernels resulted in a higher concentration of ash (Andersson et al. 1999; Xue et al. 1997) which confirms that minerals are present in the hull. For HB, ash concentration was significantly affected by genotype at each PL (Figure 4.26). The normal starch HB genotype McGwire had significantly lower ash concentration compared to all modified starch genotypes at all PL except at PL3 where it had a similar ash levels to the waxy starch genotypes, Alamo, Fibar, and Rattan. However, this finding is not in agreement with other researchers who found no significant differences in ash levels between normal and waxy starch HB genotypes (Yeung & Vasanthan, 2001; Xue et al. 1997). At PL3, a significantly higher concentration of ash was observed in HA starch genotypes compared to waxy starch genotypes.

Figure 4.25. Effect of pearling level within genotype on mean ash concentration (dry weight basis) of selected Western Canadian barley varieties



Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.26. Effect of genotype within pearling level on mean ash concentration (dry weight basis) of selected Western Canadian hulless barley varieties



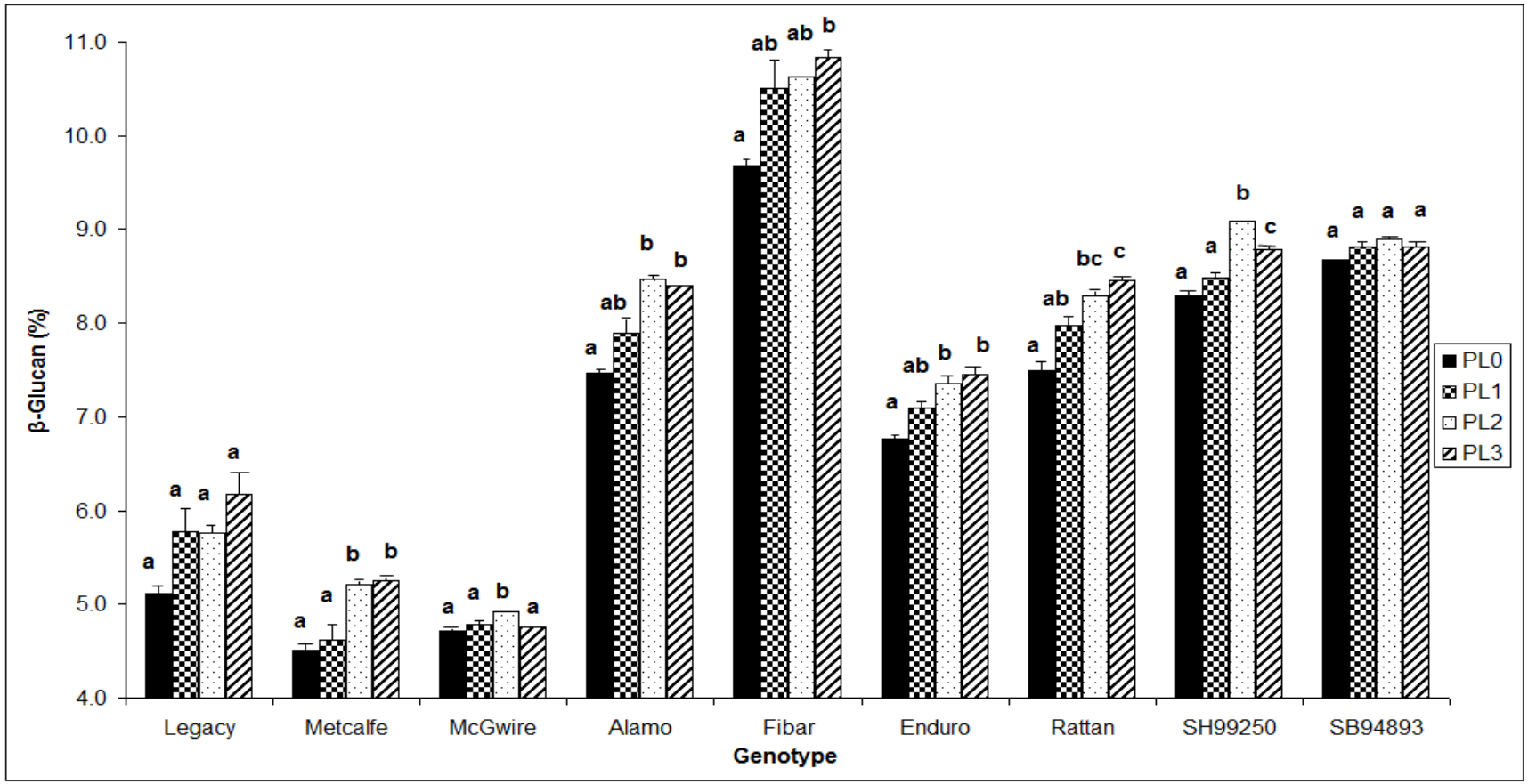
Different letters (a, b, c, d, e, f) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

4.1.2.4. β-Glucan

For most genotypes, β-glucan concentration was significantly affected by the level of pearling applied (Figure 4.27). The β-glucan content significantly increased from PL0 to PL2 for all genotypes with the exception of the hulled genotype, Legacy, the waxy starch genotype Fibar, and the HA starch genotype SB94893. Klamczynski et al. (1998) and Bhatty & Rossnagel (1998) also found that increased levels of pearling resulted in barley with higher β-glucan levels. The cell walls of the aleurone and starchy endosperm contain 26 and 75% β-glucan, respectively (Trogh et al. 2007) which explains why higher β-glucan content is observed at increased levels of pearling. Thus, by pearling, β-glucan concentration may be increased resulting in an enhanced nutritional profile.

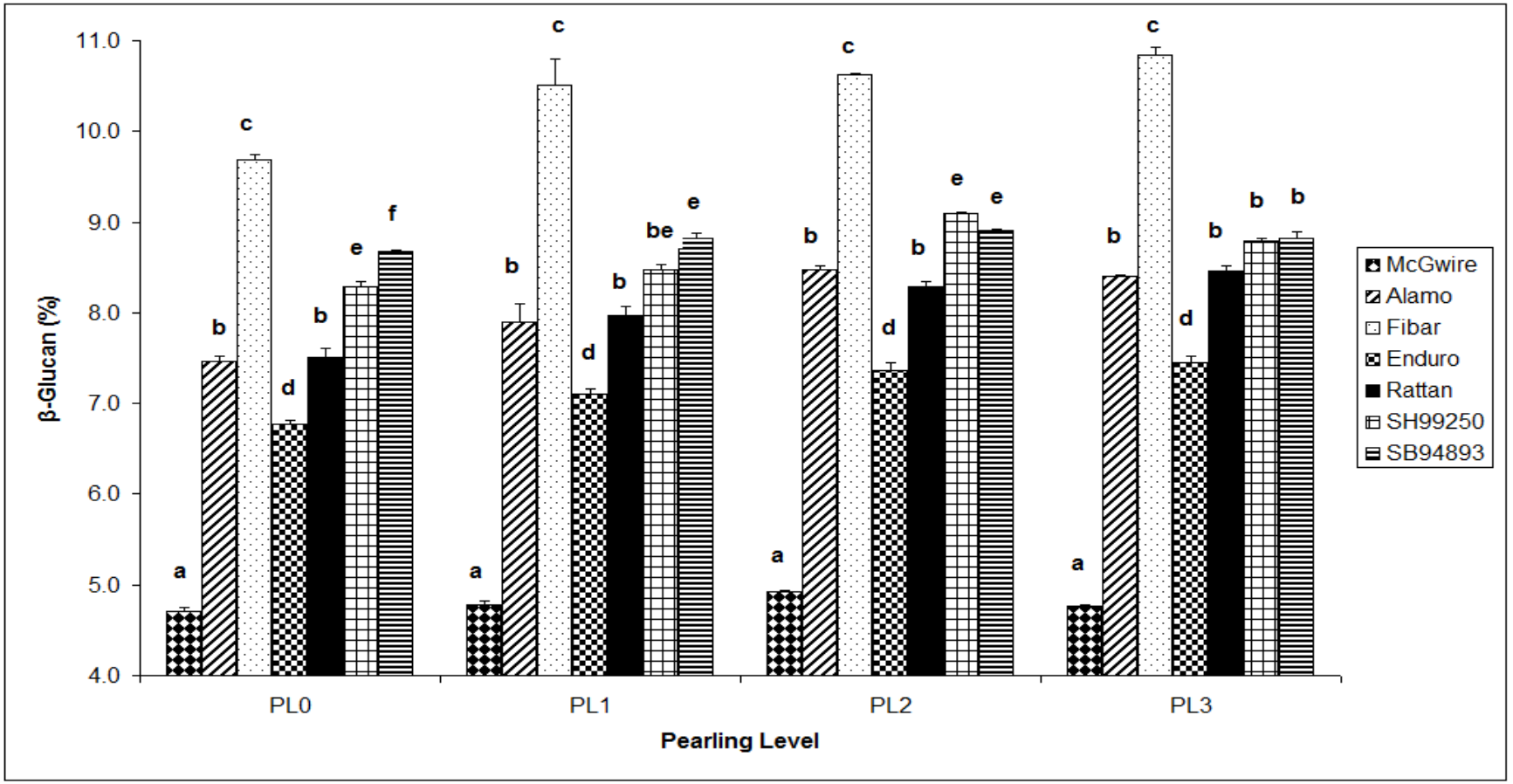
Hulled barley genotypes (Legacy and Metcalfe) had a lower β-glucan concentration compared to HB with modified starch characteristics (Figure 4.27). These findings are in agreement with results published by other researchers (Jood & Kalra, 2001; Andersson et al. 1999; Bhatty 1993). Figure 4.28 shows that the normal starch HB McGwire had significantly lower levels of β-glucan than other HB genotypes at all levels of pearling which is supported by findings of others (Gray 2009; Box et al. 2007; Rossnagel, 2005; Yeung & Vasanthan, 2001). It is well known that barley genotypes with modified starch characteristics have a higher concentration of β-glucan compared to genotypes with normal starch characteristics.

Figure 4.27. Effect of pearling level within genotype on mean β-glucan concentration (dry weight basis) of selected Western Canadian barley varieties



Different letters (a, b, c) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.28. Effect of genotype within pearling level on mean β-glucan concentration (dry weight basis) of selected Western Canadian hulless barley varieties



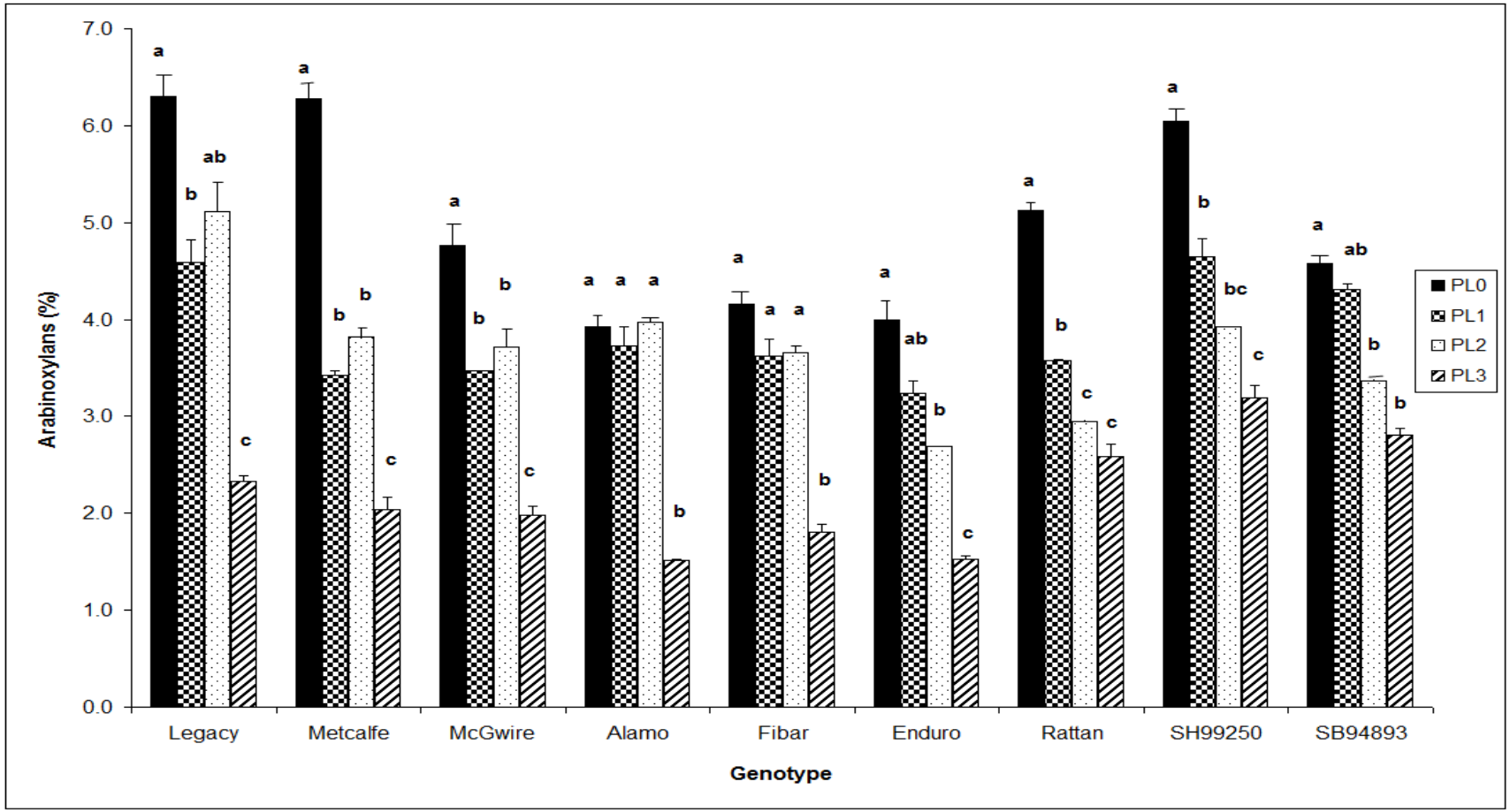
Different letters (a, b, c, d, e, f) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

Significant differences in β-glucan concentration were found among HB genotypes with varying starch characteristics (Figure 4.28). In particular, the waxy starch genotype, Fibar, contained a significantly higher level of β-glucan compared to other HB genotypes at all PL. In contrast, at all PL, the waxy starch genotype, Enduro, had a significantly lower level of β-glucans than other modified starch HB genotypes. At PL0 and PL2, HA starch genotypes were significantly higher in β-glucan content compared to other genotypes except for waxy genotype, Fibar.

4.1.2.5. Arabinoxylans

Arabinoxylan concentration was significantly affected by pearling level for all barley genotypes (Figure 4.29). All genotypes had significantly higher levels of arabinoxylans at PL0 compared to PL3 due to the presence of the arabinoxylan rich outer layer present in the unpearled kernel. This can be explained by the fact that the majority of arabinoxylans are found in the outer layers of the kernel (pericarp, testa & aleurone) and the remainder are located within the endosperm (Izydorczyk and Biliaderis, 2006). Thus, with increased levels of pearling, more outer tissues are removed resulting in a decreased concentration of arabinoxylans. Hashimoto et al. (1987) found a significant decrease in arabinoxylan concentration when 15% of the outer layer was removed from barley. For all genotypes except HA starch genotypes SH99250 and SB94893 and waxy starch genotype Rattan, a significant decrease in arabinoxylan concentration was observed between PL2 and PL3. A higher concentration of arabinoxylans was found in unpearled hulled barley compared to HB. Xue et al. (1996) also found that hulled barley had a higher concentration of arabinoxylans compared to HB.

Figure 4.29. Effect of pearling level within genotype on mean arabinoxylan concentration (dry weight basis) of selected Western Canadian barley varieties



Different letters (a, b, c) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

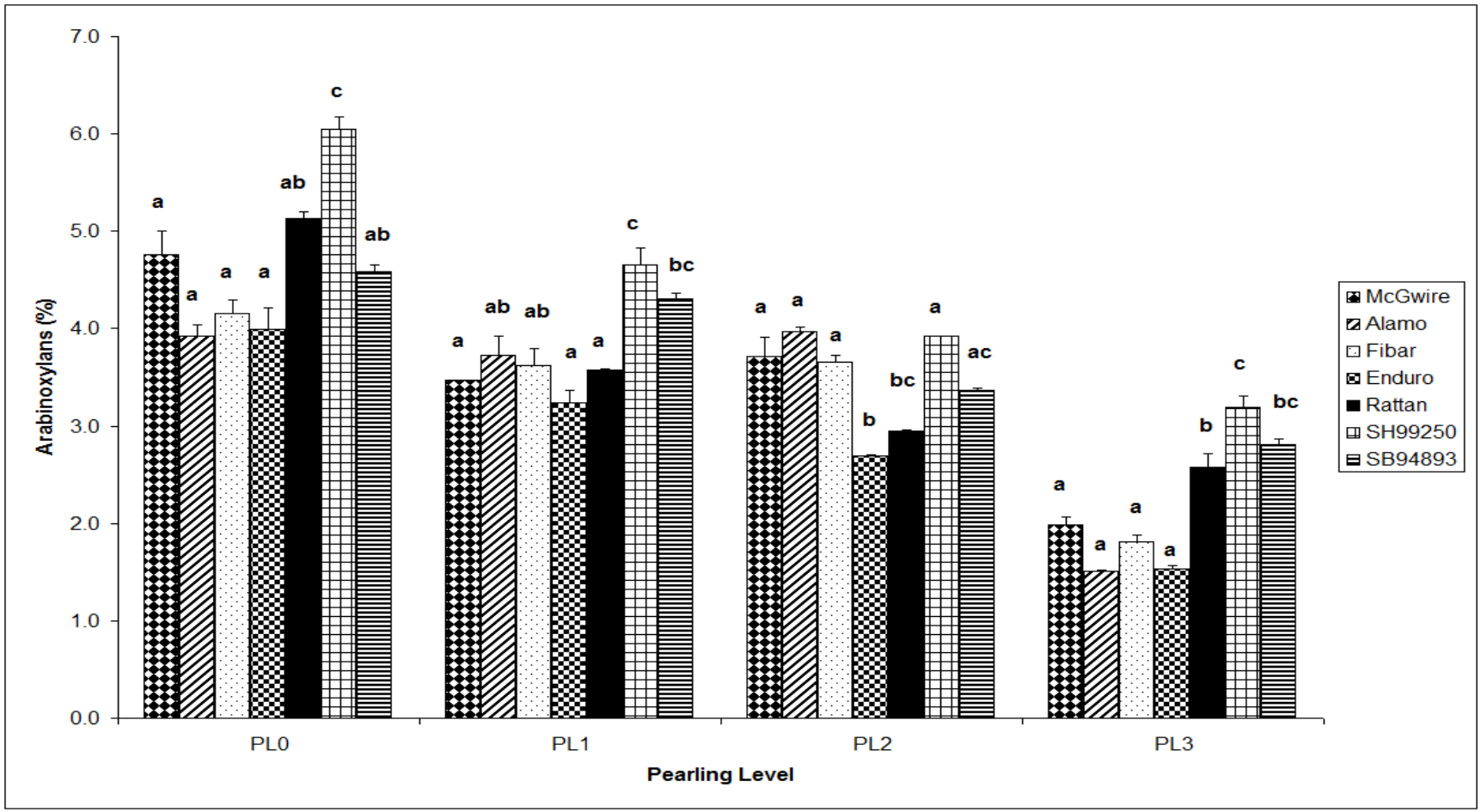
No consistent trend was observed in arabinoxylan concentration among genotypes with differing starch characteristics at each PL (Figure 4.30). Andersson et al. also did not find any significant differences in arabinoxylan concentration between genotypes with waxy and HA starch characteristics.

4.1.2.6. Free phenolic acids

For all genotypes, a significantly lower concentration of free phenolic acids was observed at PL3 compared to PL0 (Figure 4.31). This can be explained by the removal of the barley kernel's outer tissues during pearling. Quinde-Axtell et al. (2006) also found that when barley kernels were subjected to pearling, the concentration of free phenolic acids decreased significantly which they also attributed to the presence of free phenolic acids in the outer tissues of the kernel.

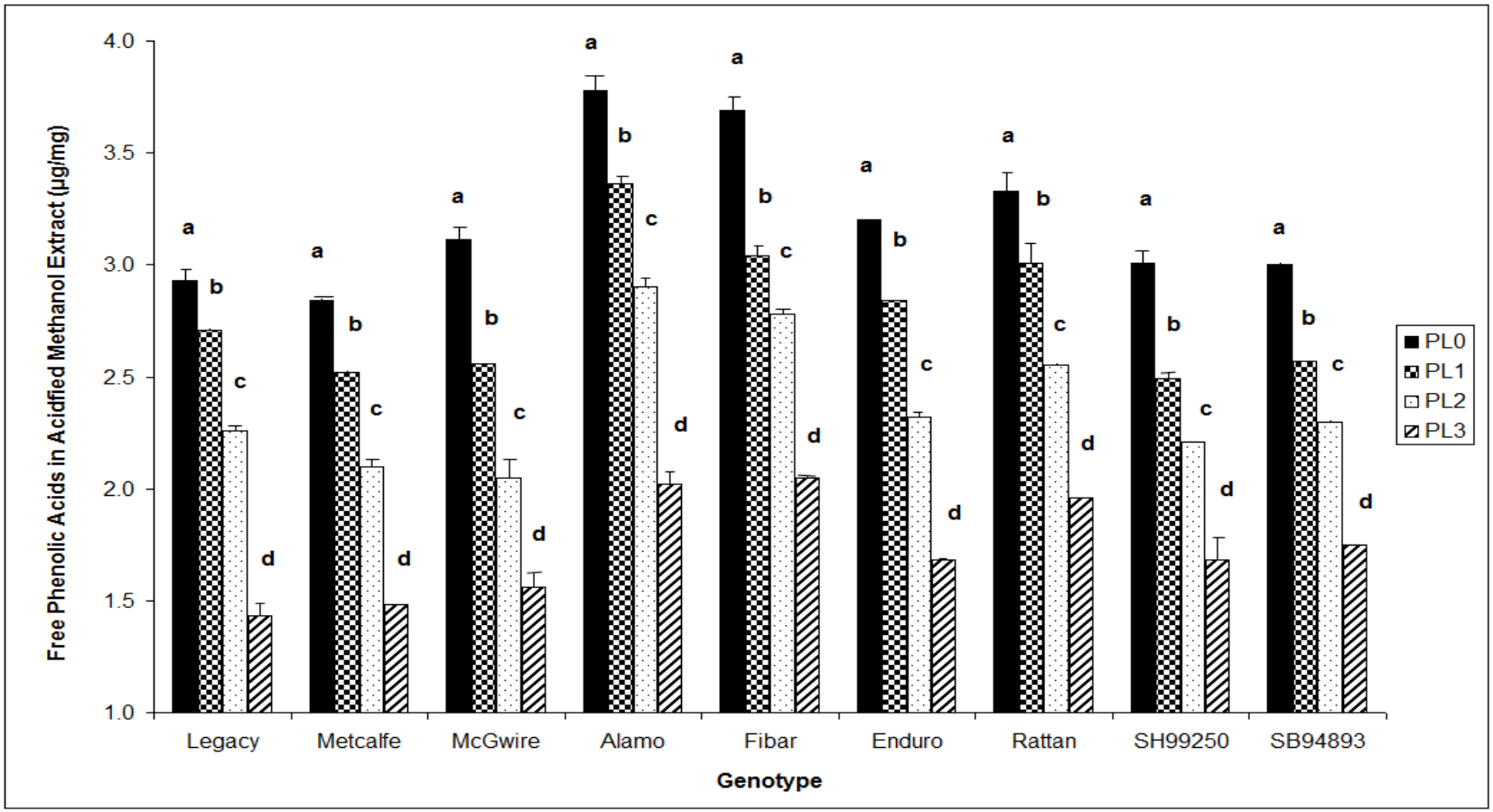
As shown in Figure 4.32, the concentration of free phenolic acids was significantly different among HB genotypes. At PL0, the waxy starch genotypes, Alamo and Fibar, were found to have a significantly higher concentration of free phenolic acids compared to other modified starch genotypes. Also at PL2 and PL3, the waxy starch genotypes, Alamo, Fibar, and Rattan were found to have a significantly higher concentration of free phenolic acids compared to normal and HA starch genotypes. This is in contrast to Holtekjolen et al. (2006) who found no significant difference in the concentration of free phenolic acids between unpearled waxy and HA starch genotypes.

Figure 4.30. Effect of genotype within pearling level on mean arabinoxylan concentration (dry weight basis) of selected Western Canadian hulless barley varieties



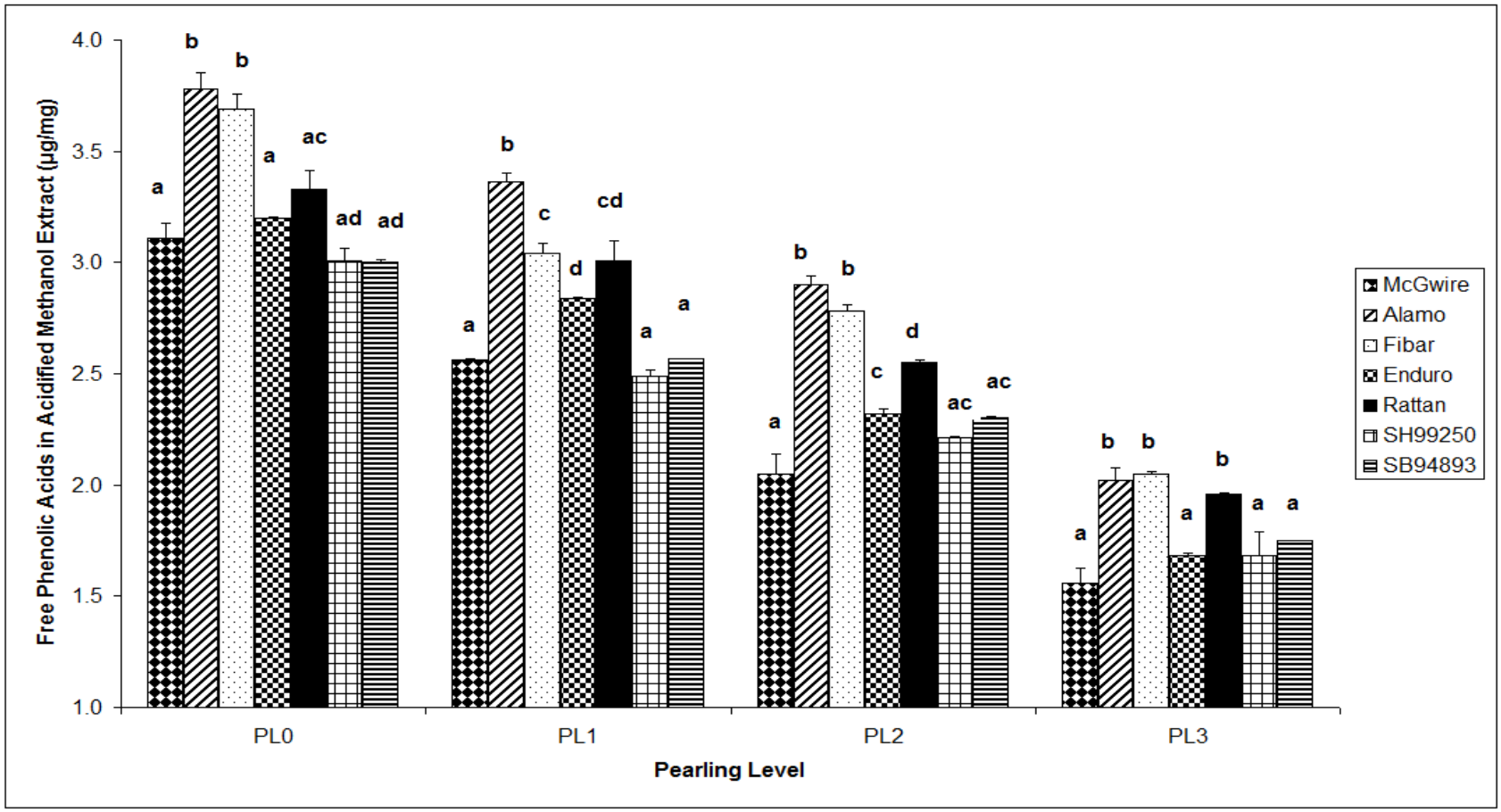
Different letters (a, b, c) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

Figure 4.31. Effect of pearling level within genotype on mean free phenolic acid concentration (dry weight basis) in acidified methanol extract of selected Western Canadian barley varieties



Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.32. Effect of genotype within pearling level on mean free phenolic acid concentration (dry weight basis) in acidified methanol extract of selected Western Canadian hulless barley varieties



Different letters (a, b, c, d) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

4.2. EFFECTS OF PEARLING LEVEL AND GENOTYPE ON THE TECHNOLOGICAL AND SENSORY PROPERTIES OF COOKED BARLEY

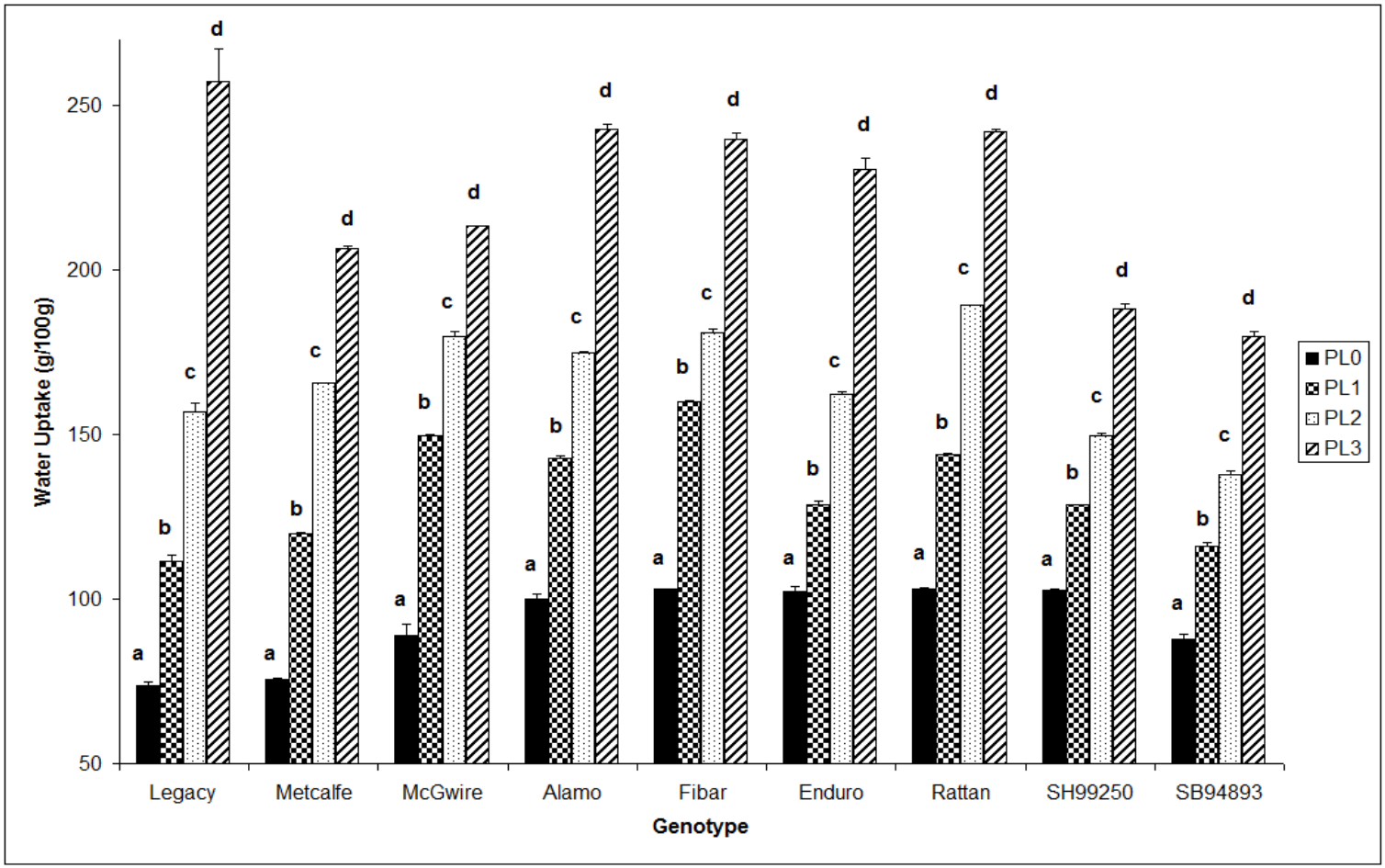
Water uptake, brightness, and firmness of cooked kernels were evaluated at three different cooking times (20, 30, and 40 min). Only results for barley cooked for 30 min are shown since similar results were found for the other two cooking times. Appendix F provides the statistical results for the three cooking times for water uptake, brightness, and firmness of cooked barley kernels. Appendix D provides results of one-way ANOVA for technological and sensory properties of cooked barley.

4.2.3. Water uptake during cooking of barley kernels

For all barley genotypes, the water uptake of barley kernels significantly increased with increasing PL (Figure 4.33). Klamczynski et al. (1998) demonstrated that when level of pearling was increased from 0% to 40% of kernel removed, the water uptake of kernels significantly increased when monitored over a 24 h soaking period. It appears that the partial or complete removal of the outer layers of barley exposes the starchy endosperm and improves water penetration and absorption during cooking.

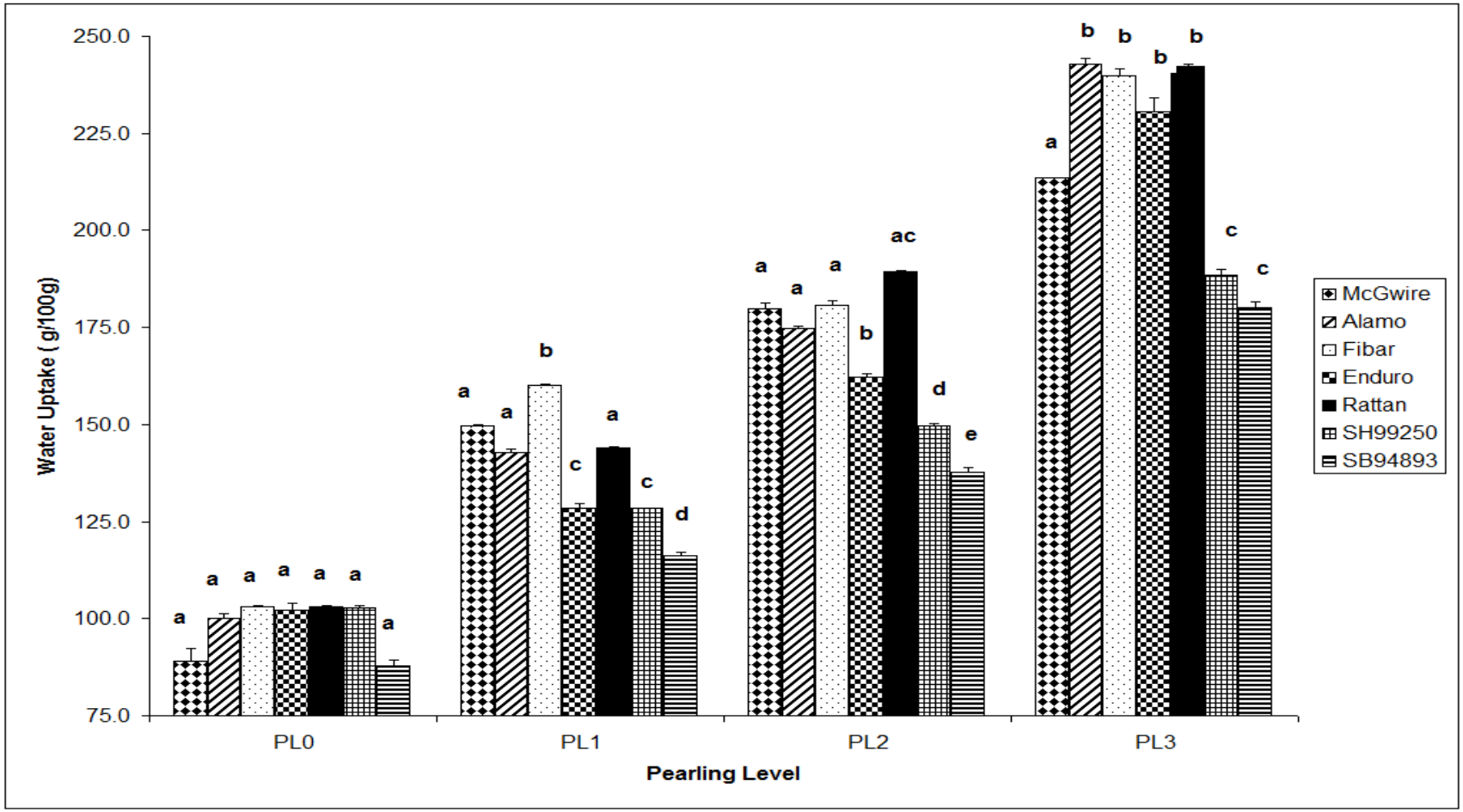
Water uptake during cooking was significantly affected by genotypic differences at all three PL (1-3) but no differences in water uptake were observed among genotypes for unpearled barley (PL 0) (Figure 4.34). After pearling, significantly greater water uptake was noted for normal and waxy starch varieties than for HA starch genotypes. This can be explained by the fact that amylopectin contributes to swelling, whereas, amylose suppresses it and maintains the integrity of swollen starch granules (Yasui, 2002).

Figure 4.33. Effect of pearling level within genotype on mean water uptake of selected Western Canadian barley varieties cooked for 30 min



Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.34. Effect of genotype within each pearling level on mean water uptake of selected Western Canadian hulless barley varieties cooked for 30 min



Different letters (a, b, c, d, e) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

Another factor contributing to the lower water uptake of HA starch barley kernels could be their higher hardness index compared to that of normal and waxy starch barley kernels (Table 4.1). Gamlath et al. (2008) found that harder barley kernels absorb water less rapidly than softer kernels.

4.2.4. Brightness of cooked barley kernels

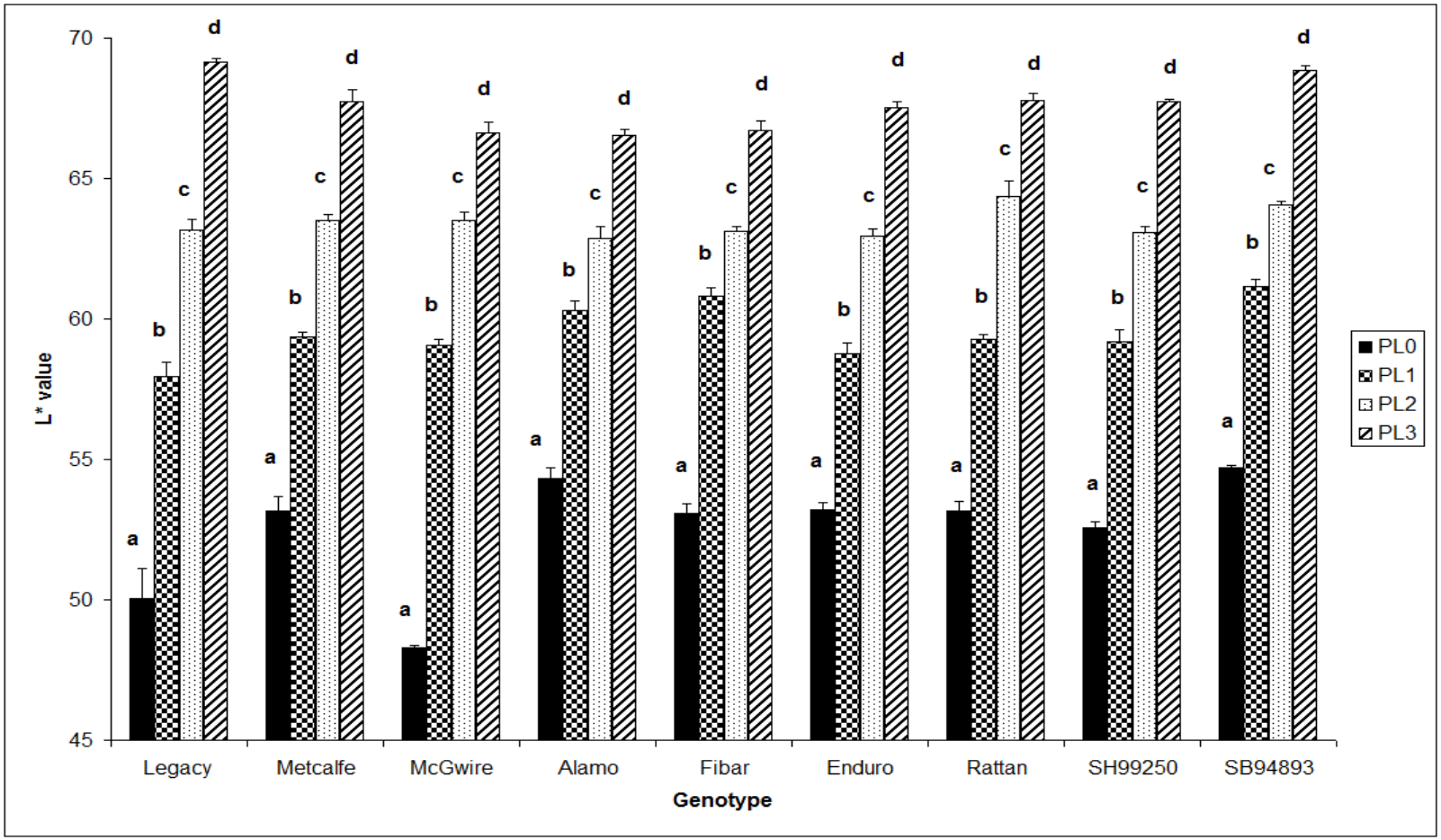
Figure 4.35 shows that increasing the PL significantly improved the brightness of cooked barley kernels regardless of genotype. A strong positive correlation ($r = 0.85$) was observed between uncooked and cooked barley kernels when brightness was examined with the colorimeter. This correlation can be observed by examining trends in Figure 4.19 and 4.35 which show that as pearling level increased, the brightness also increased.

Some differences in brightness of cooked barley kernels were observed among genotypes (Figure 4.36). At PL0, the cooked kernels of McGwire had significantly lower L* values than other HB genotypes but after pearling the differences in brightness among genotypes were less pronounced. Figure 4.36 also shows that uncooked kernels of waxy starch barley were not significantly brighter than those of normal and HA starch genotypes but in uncooked barley kernels significant differences were observed (Figure 4.20).

4.2.5. Firmness of cooked barley kernels

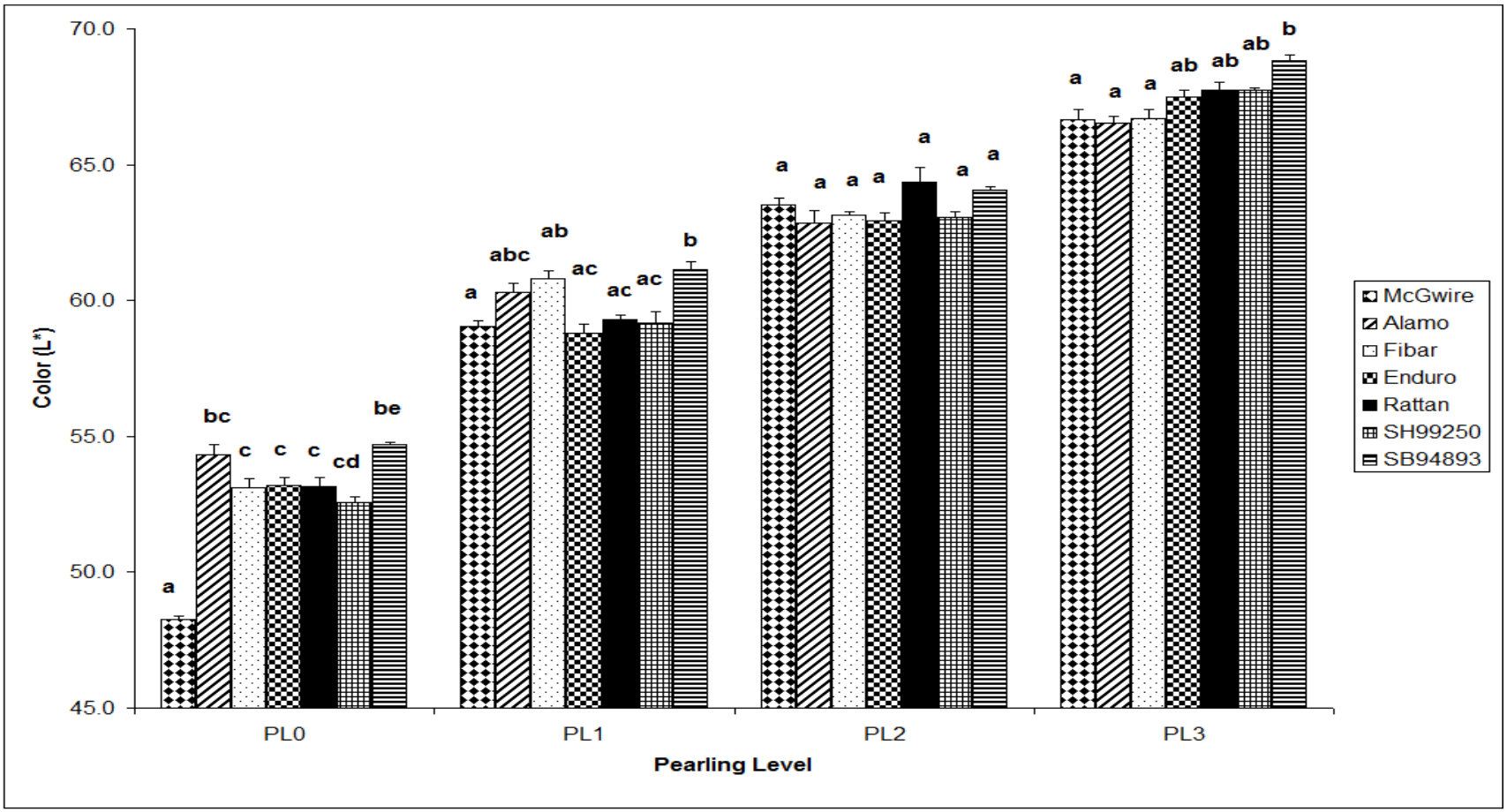
As expected, for all genotypes the unpearled barley kernels (PL0) were significantly firmer than pearled barley kernels (PL1-3) (Figure 4.37). For all genotypes,

Figure 4.35. Effect of pearling level within genotype on mean brightness of selected Western Canadian barley varieties cooked for 30 min



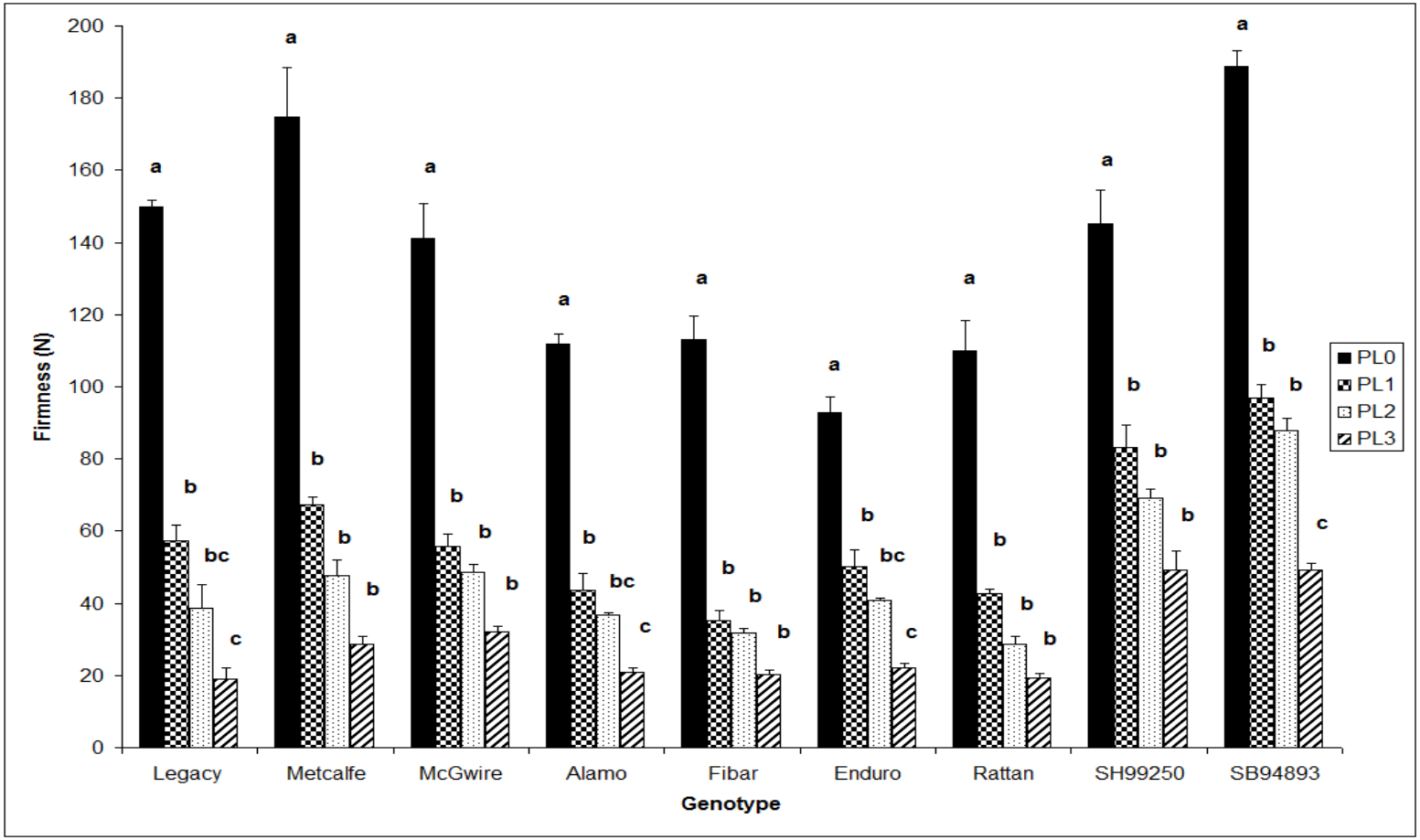
Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

Figure 4.36. Effect of genotype within each pearling level on mean brightness of selected Western Canadian hulless barley varieties cooked for 30 min



Different letters (a, b, c, d, e) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

Figure 4.37. Effect of pearling level within genotype on mean firmness of selected Western Canadian barley varieties cooked for 30 min



Different letters (a, b, c) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

no significant differences in firmness were observed between PL1 and PL2 but the HA starch SB94893 was significantly softer at PL3 than at PL1.

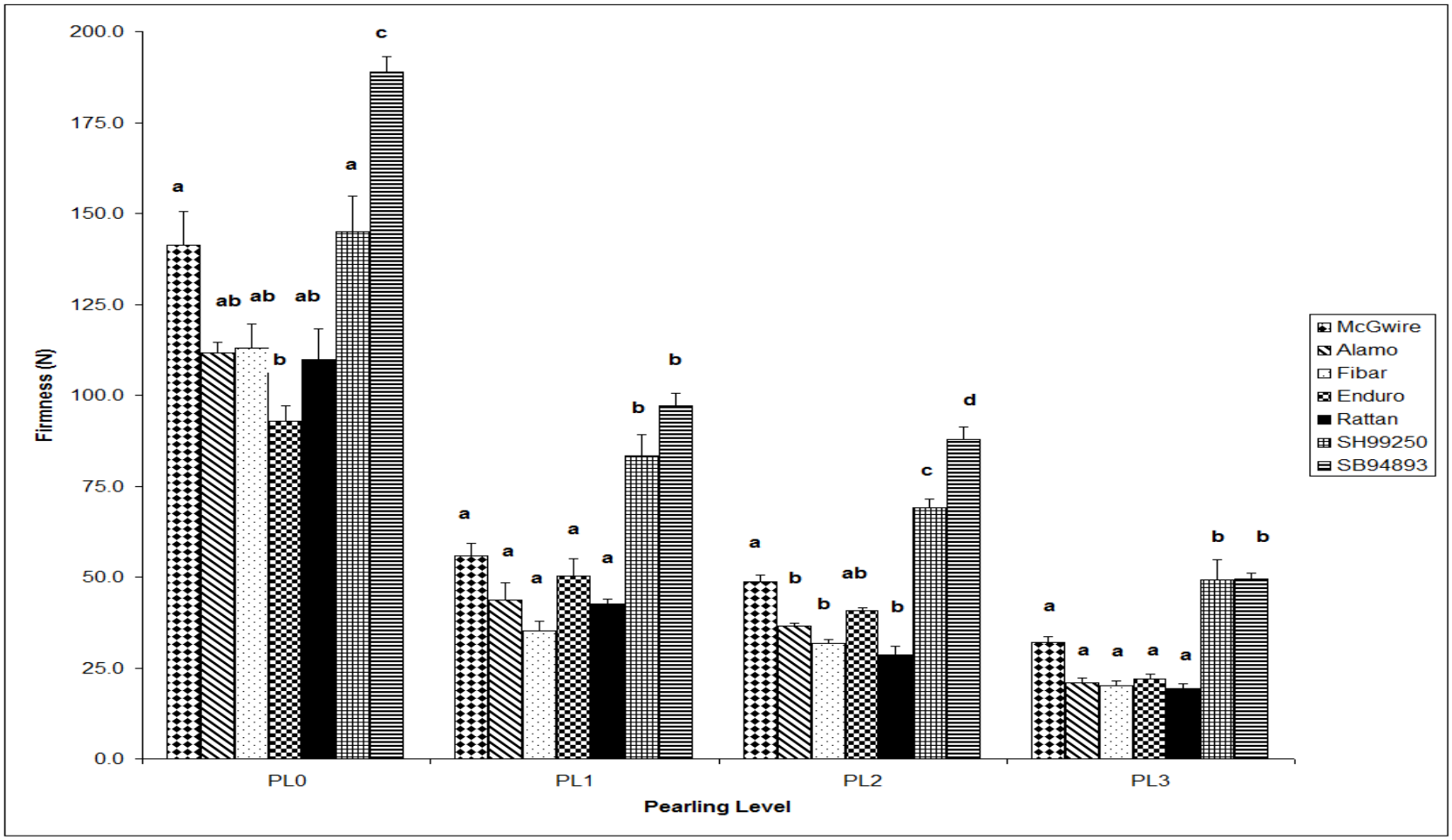
Differences in firmness of cooked kernels were observed among the HB genotypes (Figure 4.38). The cooked kernels of HA starch genotypes were significantly firmer than other samples at all three pearling levels (PL1-3). The differences in firmness of cooked barley kernels among genotypes can be attributed to differences in the ratio of amylose and amylopectin between waxy and HA starch genotypes (Klamczynski et al. 1998).

4.2.6. β-Glucan loss during cooking and solubility of β-glucans in cooked barley kernels

β-Glucans are important constituents of barley which contribute to the associated health benefits of barley. Thus, β-glucan loss during food processing should be minimized. The β-glucan concentration in cooked barley kernels (PL0) was compared to uncooked barley kernels to determine the effect of cooking time, PL, and genotype on the loss of these polysaccharides after cooking.

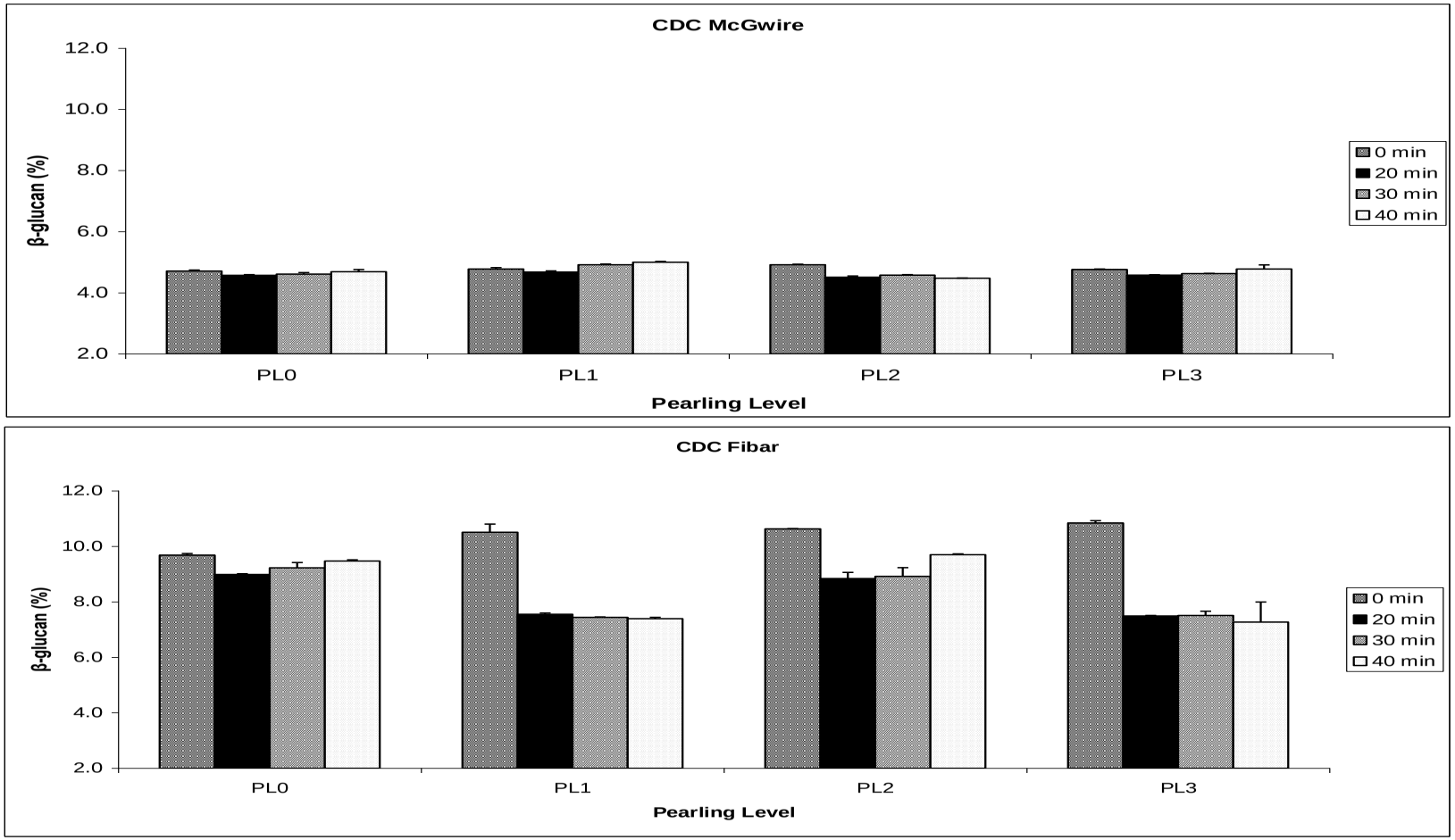
The effects of cooking time on the amount of β-glucan retained in the kernels are shown in Figure 4.39 for two barley genotypes: McGwire with normal starch characteristics and a relatively low level of β-glucans and Fibar with waxy starch characteristics and elevated levels of β-glucans. For McGwire, there was no substantial loss in β-glucans with increased cooking time at each PL. For pearled Fibar, increasing the cooking time resulted in a decrease in β-glucans. There was little to no β-glucan lost in unpearled samples (PL0) across all cooking times for both McGwire and Fibar.

Figure 4.38. Effect of genotype within each pearling level on mean firmness of selected Western Canadian hulless barley varieties cooked for 30 min



Different letters (a, b, c, d) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

Figure 4.39. Effect of cooking time on the mean β-glucan solubility of CDC McGwire and CDC Fibar barley genotypes pearled to various levels

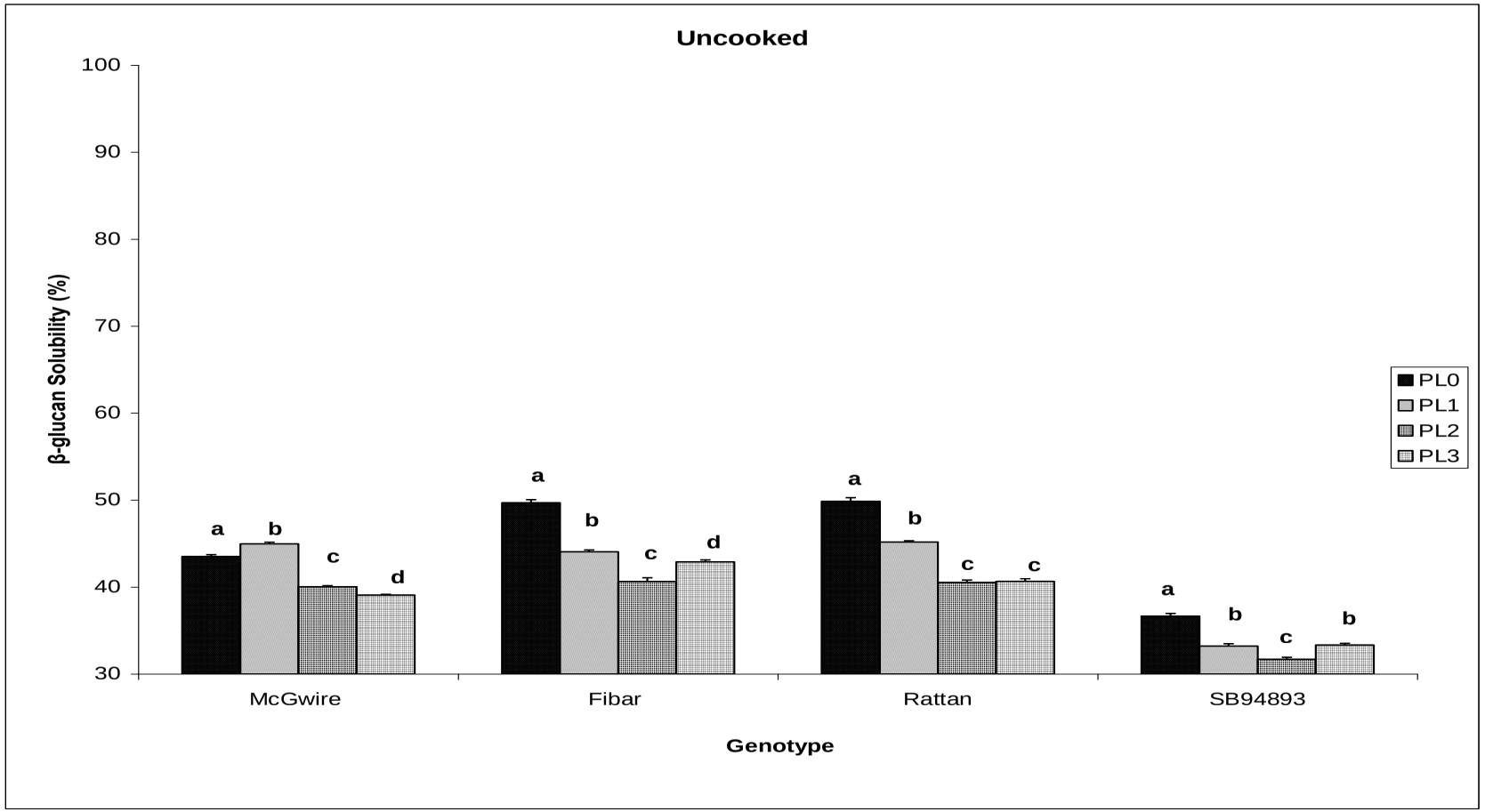


Level of outer layers removed for hulless barley samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

Overall, the concentration of β-glucans in cooked pearled barley kernels was 1-3% lower than in uncooked pearled kernels. Waxy starch barley genotypes lost slightly higher amounts of β-glucans during cooking than normal and HA starch genotypes (results not shown). It has been demonstrated that the amount of ingested β-glucans accounts only in part for their hypercholesterolemic effects and that the water solubility and viscosity building properties of these polysaccharides are critical for their efficacy in delivering the positive physiological effects (Keogh et al. 2003; Wood, 2010). The solubility/ extractability (under comparable time, temperature, pH, and other extraction conditions) of β-glucans from the grain depends on the molecular features of these polymers but it is also related to the overall composition and architecture of the cell wall assemblies. The coexistence of several biopolymers in the cell wall of cereal grains, their spatial organization, and the nature of interactions among them contribute to the mechanical strength, permeability, and therefore to solubility of the cell wall constituents, including β-glucans (Storsley et al. 2003).

In this study, the solubility of β-glucans in cooked and uncooked barley samples was tested after extraction of ground barley in excess water for 2 h at 45^{o}C. The solubility of β-glucans, expressed as percentage of total β-glucans, in uncooked HB genotypes varied from 32- 50% (Figure 4.40). The highest solubility was observed in waxy starch varieties, whereas, the lowest solubility was observed in the HA starch genotype, SB94893. With the exception of McGwire, the β-glucan solubility of uncooked barley decreased at PL1 compared to PL0. For all genotypes, β-glucan solubility decreased or remained unchanged across PL1-3.

Figure 4.40. Effect of pearling level within each genotype on mean β-glucan solubility of uncooked hulless varieties of selected Western Canadian barley



Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for hulless barley samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

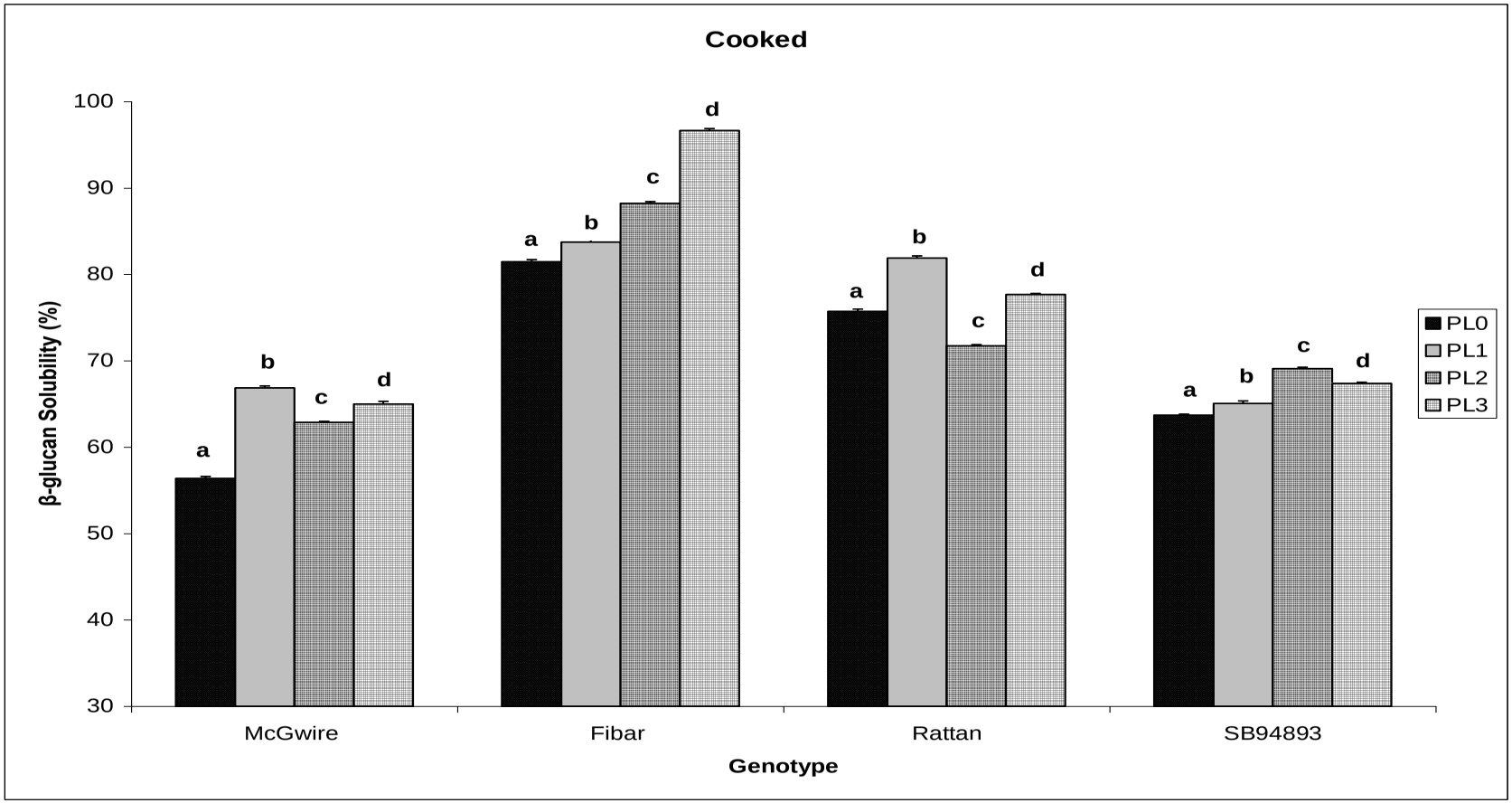
Cooking significantly increased the solubility of β-glucans to a range of 57-96% (Figure 4.41). The solubility of β-glucans in cooked samples increased with increasing pearling levels. As for uncooked barley, the highest β-glucan solubility in cooked barley was observed for waxy starch genotypes. However, cooking improved the solubility of β-glucans in the HA genotype, SB94893. After cooking, SB94893 had similar β-glucan solubility to McGwire, whereas in uncooked barley, SB94893 had lower β-glucan solubility than McGwire (Figure 4.40 & 4.41).

4.2.7. *In vitro* starch digestibility

Due to the increased focus on starchy foods and nutritional advantages of carbohydrates that are slowly digested and absorbed, the nutritional properties of different starches in barley are of interest. Differences in starch digestibility have been ascribed to various factors including the botanical source, food processing, granule size, amylose to amylopectin ratio, degree of crystallinity, the presence of amylose-lipid complexes, and to the molecular structure of starch (Chung et al. 2010). Due to the complexity of the digestive system, no *in vitro* test has been identified to fully replace *in vivo* GI testing but *in vitro* tests correlate well to the glycemic response that would occur in the human body (Germaine et al. 2008; Goni et al. 1997).

The results of the *in vitro* starch digestion of pearled barley after cooking to optimum are presented in Table 4.3. For each barley genotype tested, the amount of digestible starch within 30 min of digestion increased as PL increased. The starch digestion index (SDI), calculated as the amount of digested starch during 30 min of

Figure 4.41. Effect of pearling level within each genotype on mean β-glucan solubility of cooked hulless varieties of selected Western Canadian barley



Different letters (a, b, c, d) within the same genotype show significance (P≤0.05)
Level of outer layers removed for hulless barley samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%

digestion in relation to the total starch content in samples also increased with higher pearling levels (Table 4.3).

Table 4.3. Starch digestion index of selected varieties of pearled Western Canadian barley after being optimally cooked[a]

Barley[b]	**Total Starch** (%)	**Digestible Starch in Cooked Pearled Barley**	
		30 min (g starch/100g barley)	**SDI (%)**[c]
Legacy			
PL1	63.3 ± 0.8	9.0 ± 1.0	14.2
PL2	65.1 ± 0.7	12.2 ± 1.0	18.7
PL3	71.7 ± 0.1	15.6 ± 0.5	21.7
McGwire			
PL1	65.8 ± 0.1	11.0 ±0.5	16.7
PL2	66.6 ± 0.8	13.2 ± 0.2	19.8
PL3	71.3 ± 1.2	14.8 ±0.3	20.7
Fibar			
PL1	53.3 ± 1.1	11.3 ±0.3	21.1
PL2	55.0 ± 0.6	12.4 ± 0.1	22.5
PL3	59.9 ± 1.2	14.6 ± 2.1	24.4
Rattan			
PL1	57.7 ± 1.0	11.1 ± 0.8	19.2
PL2	61.3 ± 1.9	13.6 ± 1.2	22.2
PL3	64.9 ± 0.1	16.4 ± 1.5	25.3
SB94893			
PL1	54.3 ± 0.6	5.3 ± 1.6	9.7
PL2	55.4 ± 0.7	7.2 ± 0.1	13.0
PL3	60.3 ± 0.3	9.8 ± 0.9	16.3

[a] Mean: n=2

[b] Level of outer layer removed: for HB samples; PL1- 5%, PL2- 10%, PL3- 25% and for hulled barley samples; PL1- 10%, PL2- 15%, PL3- 30%

[c] SDI: Starch digestion index; calculated by amount of starch digested during the first 30 min / total starch content x 100.

These results indicate that removal of the outer layers of the kernel improves the accessibility of α-amylase to its substrates. Large differences in starch digestibility were observed among different barley genotypes. The lowest level of digestible starch and the lowest SDI were observed for the HA starch genotype SB94983, whereas the highest SDI was observed for waxy starch genotypes Fibar and Rattan. These results showed that the amylose content in barley was inversely related to the amount of rapidly digestible starch (with 30 min of digestion).

Similar relationships between amylose content and starch digestibility in barley and other cereals have been reported (Gray et al. 2009). The branched structure of amylopectin is more susceptible to hydrolysis than the nearly linear structure of amylose which suggests that waxy starch genotypes have a higher level of rapidly digestible starch present than HA starch genotypes leading to a higher SDI (Vasanthan et al. 2004; Fardet et al. 2006). It has been suggested that amylose content has an influence on starch digestion, as well as glycemic response in humans (Gray et al. 2009; Ells et al. 2005).

4.2.8. Sensory evaluation

A trained sensory panel was used to determine the effect of PL and genotype on cooked barley properties. Brightness, kernel to kernel adhesion, firmness, flavor, and overall quality were assessed by the panel. Sensory assessment of the cooked barley was important because it allowed instrumental findings for brightness and firmness to be validated. It also allowed for measurements which are difficult to measure instrumentally to be determined, such as kernel to kernel adhesion, flavor, and overall quality. Barley samples were evaluated against a reference sample of commercially pearled barley.

Brightness, kernel to kernel adhesion, and firmness of cooked barley were significantly affected by panelist, genotype, and PL and the interaction of genotype and PL, whereas, only PL and genotype were found to be significant for flavor of cooked barley samples (Appendix C). No significant differences were observed for overall quality. Results for overall quality had a high standard error which indicates that there was high variability among panelists for this parameter. Therefore, the sensory data for overall quality is not presented.

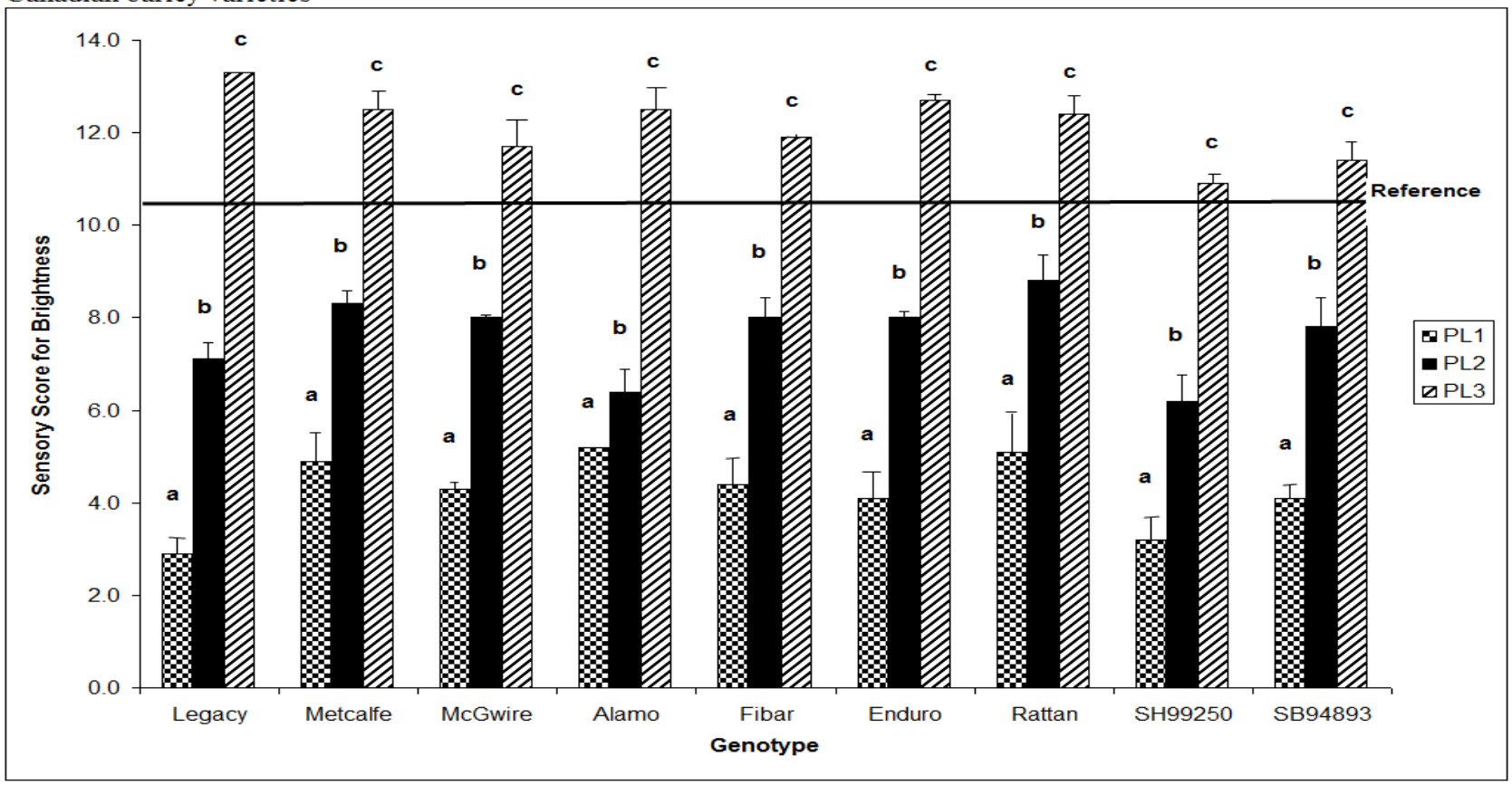
4.2.8.1. Brightness

For all genotypes, kernel brightness increased as PL increased (Figure 4.42). At PL3, higher brightness scores were found for all genotypes compared to the commercial pearled barley sample that was used as a reference.

For brightness at each PL, only a few significant differences were observed among genotypes (Figure 4.43). At PL1, HA starch genotype SH99250 was rated significantly less bright than the waxy starch genotypes, Rattan and Alamo. At PL2, waxy starch genotype, Rattan was rated significantly brighter than waxy starch genotype, Alamo and HA starch genotype, SH99250. At PL3, waxy starch genotypes, Alamo and Enduro were found to be significantly brighter than HA starch genotypes, SH99250 and SB94893 and waxy starch genotypes, Fibar and Rattan were significantly brighter than HA starch genotype, SH99250. Thus, in general, the trained panel found waxy starch genotypes to be brighter in appearance than the HA starch genotypes.

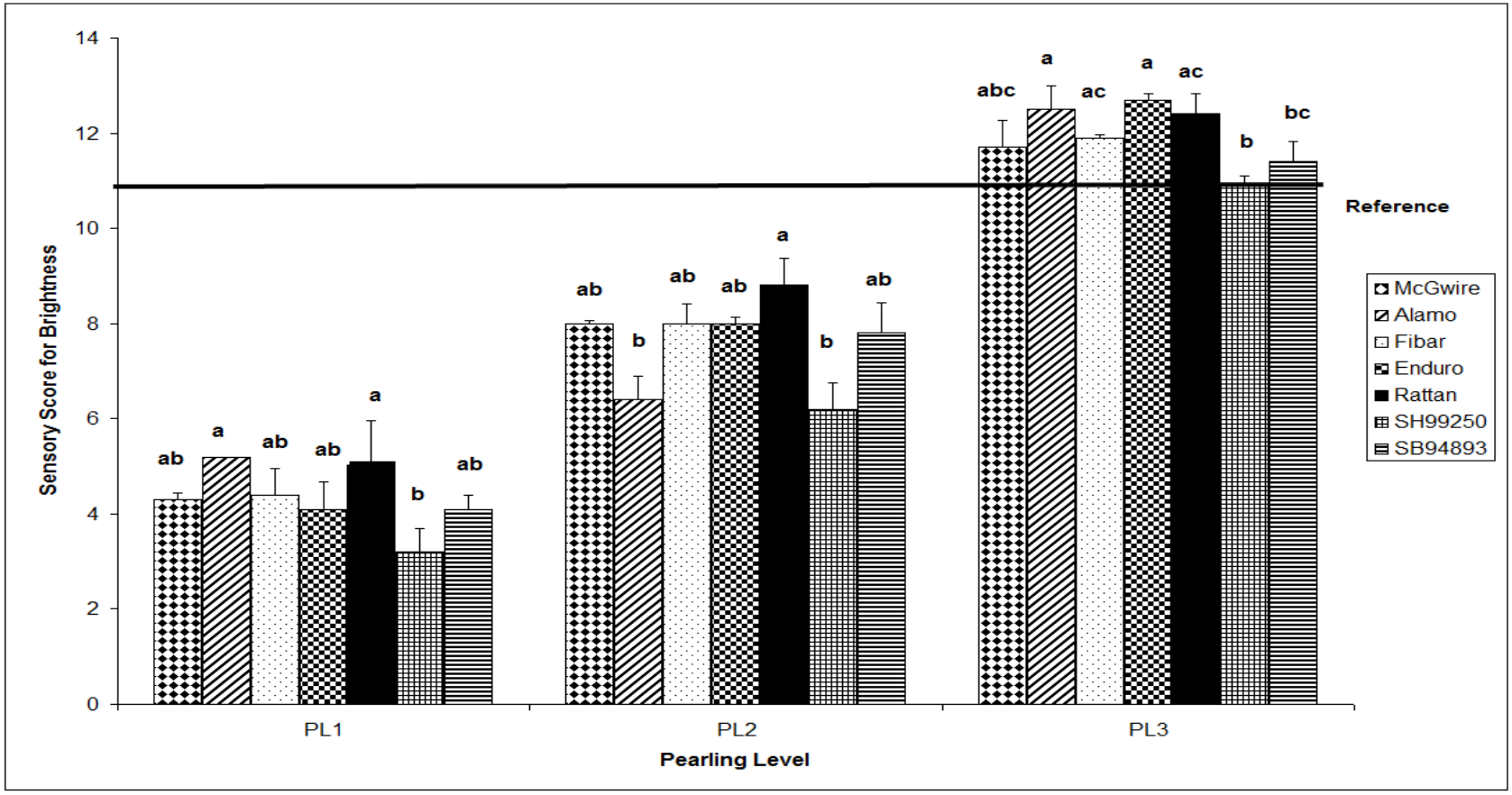
Both uncooked and cooked barley kernels were also determined instrumentally for brightness using a colorimeter. Brightness as assessed by the trained panel agreed with findings for cooked barley determined instrumentally in that as PL increased, the

Figure 4.42. Effect of pearling level within each genotype on mean sensory scores for brightness of selected Western Canadian barley varieties



Different letters (a, b, c) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%
Reference was commercially pearled barley

Figure 4.43. Effect of genotype within each pearling level on mean sensory scores for brightness of selected Western Canadian hulless barley varieties



Different letters (a, b, c) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Reference was commercially pearled barley

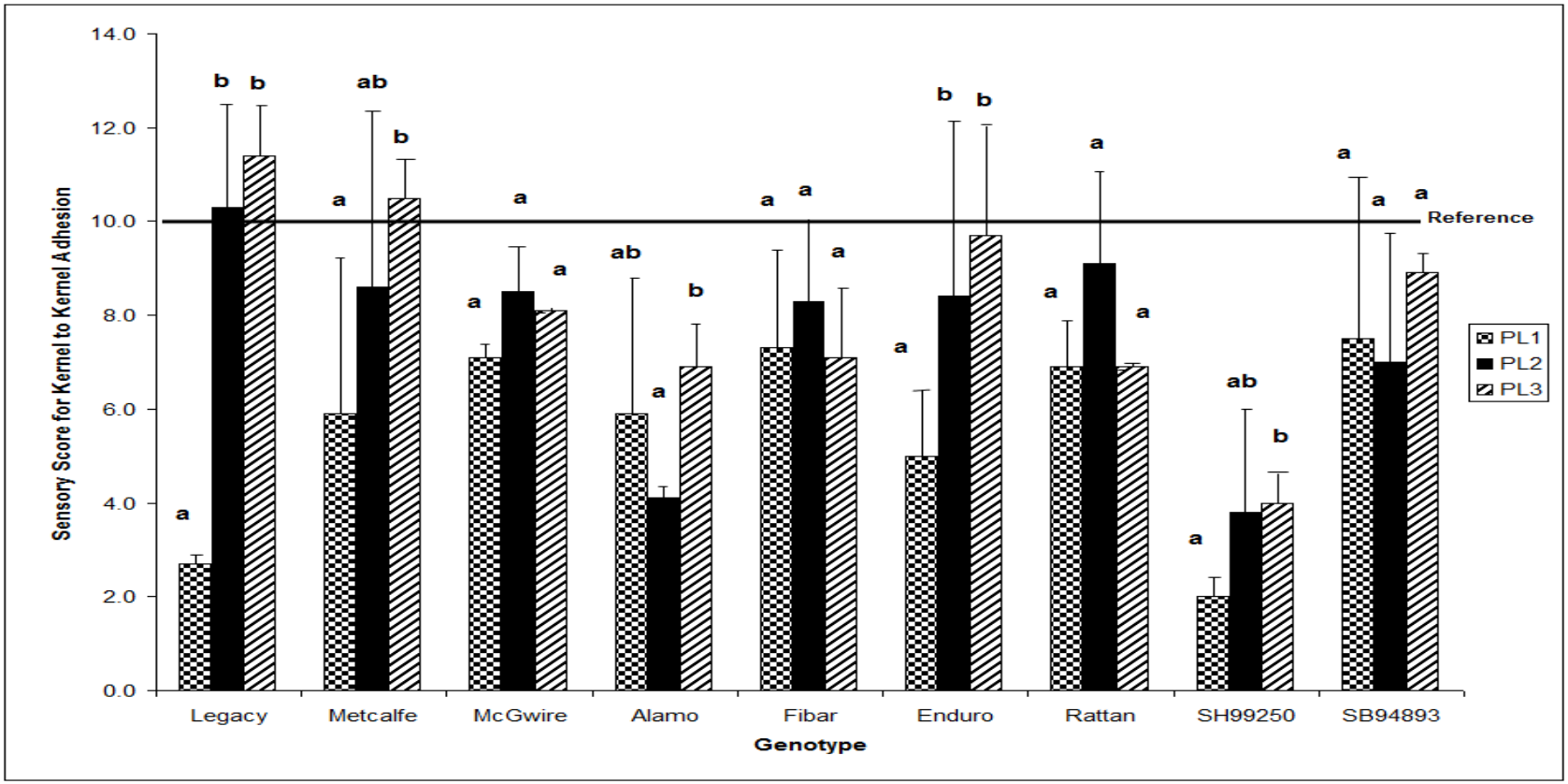
brightness also increased. Instrumentally, no significant differences were observed between cooked HB with differing starch characteristics, whereas, the trained panel detected that some of the waxy starch genotypes were significantly brighter than HA starch genotypes.

4.2.8.2. Kernel to kernel adhesion

As PL increased, panelists perceived an increase in kernel to kernel adhesion for hulled genotypes Legacy and Metcalfe, waxy starch HB genotype Enduro, and HA starch HB genotype SH99250 (Figure 4.44). However, panelists did not detect differences in kernel to kernel adhesion between samples pearled to PL1 and PL3 for normal starch genotype McGwire, waxy starch genotypes Alamo, Fibar and Rattan, and HA starch genotype SB94893.

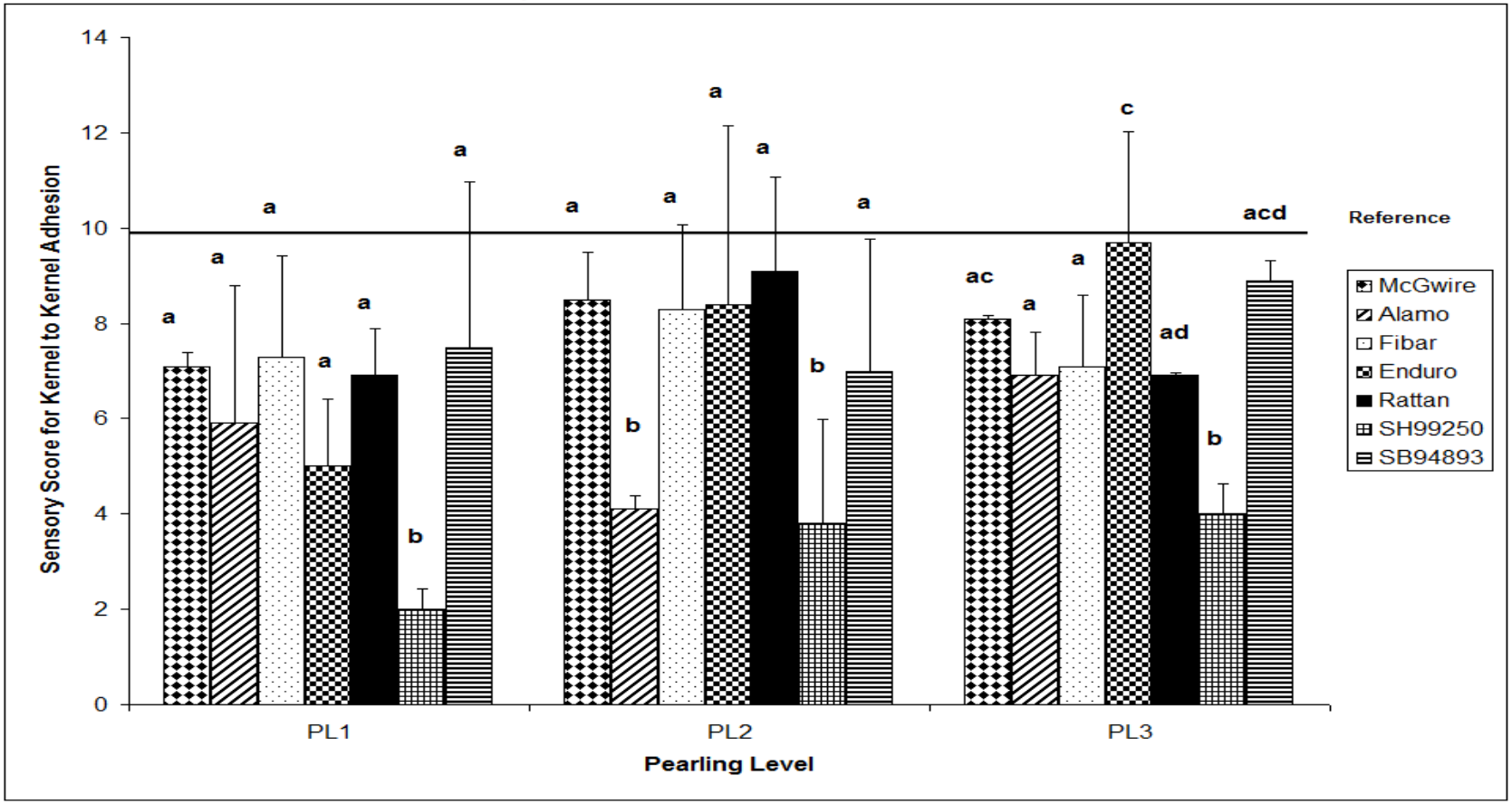
Figure 4.45 shows the effect of genotype on sensory ratings of kernel to kernel adhesion within each PL. At PL1, panelists did not perceive differences in kernel to kernel adhesion among genotypes with the exception of the HA starch genotype, SH99250 which had significantly lower kernel to kernel adhesion. For PL2, Alamo and SH99250 had significantly lower levels of kernel to kernel adhesion, whereas for PL3, SH99250 had the lowest levels. Differences in kernel to kernel adhesion properties between waxy and HA starch barley genotypes may be attributed partly to different amylose to amylopectin ratios and partly to differences in solubility of other barley components such as β-glucans. Waxy starch genotypes contain high levels of amylopectin whereas HA starch genotypes contain high levels of amylose which may explain differences observed in kernel to kernel adhesion.

Figure 4.44. Effect of pearling level within each genotype on mean sensory scores for kernel to kernel adhesion of selected Western Canadian barley varieties



Different letters (a, b) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%
Reference was commercially pearled barley

Figure 4.45. Effect of genotype within each pearling level on mean sensory scores for kernel to kernel adhesion of selected Western Canadian hulless barley varieties



Different letters (a, b, c, d) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Reference was commercially pearled barley

4.2.8.3. Firmness

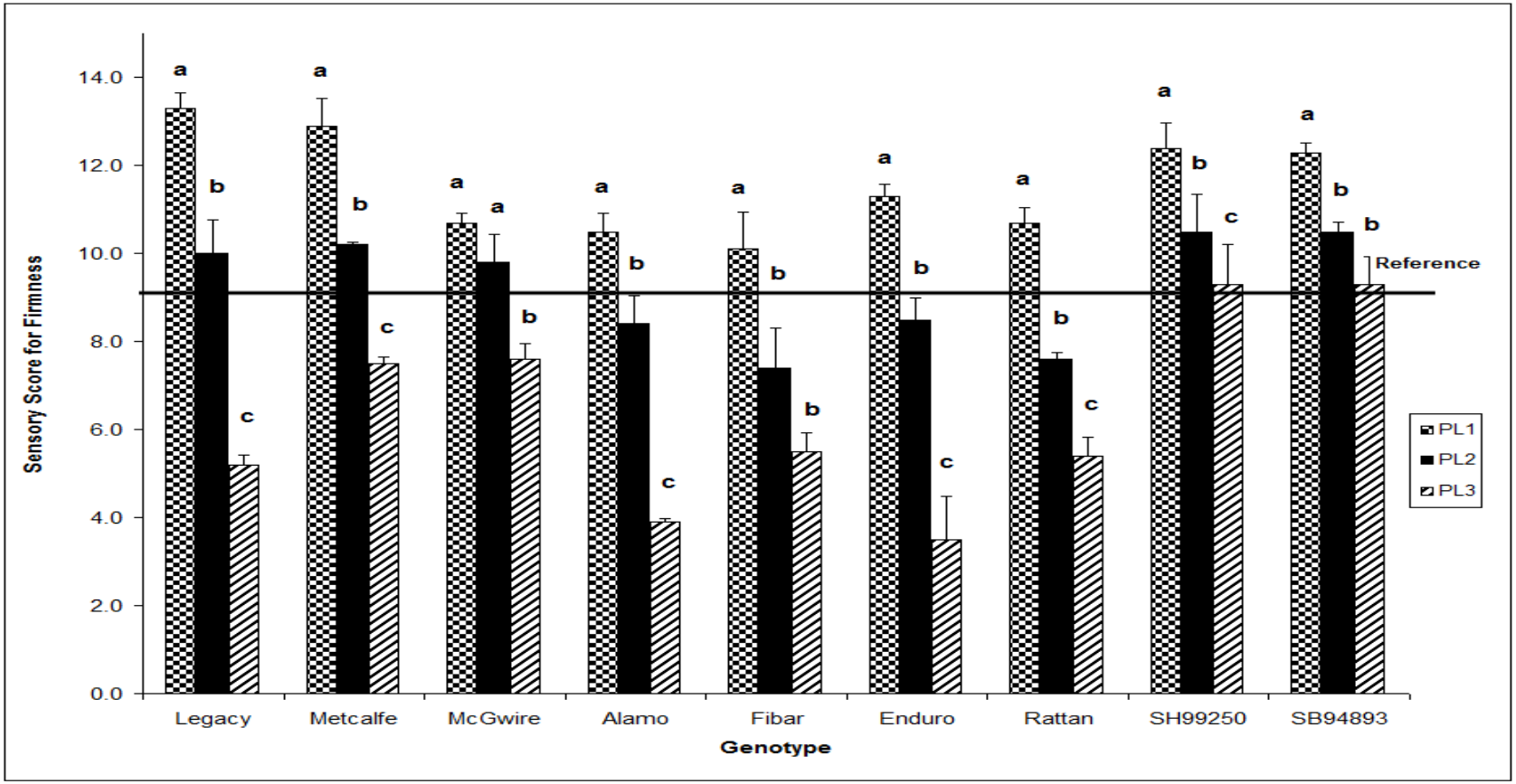
Firmness significantly decreased across PL for all genotypes (Figure 4.46) which is in agreement with instrumental findings for cooked firmness. Thus, there is strong evidence that PL has a significant effect on the cooked firmness of barley.

Firmness was significantly different for HB genotypes with varying starch characteristics (Figure 4.47). For each PL, there was no significant difference among waxy starch genotypes. For all levels of pearling, HA starch genotypes had firmer scores than normal and waxy starch genotypes but were not significantly different in all cases. The higher firmness scores for HA starch genotypes were in agreement with firmness values determined instrumentally.

4.2.8.4. Flavor

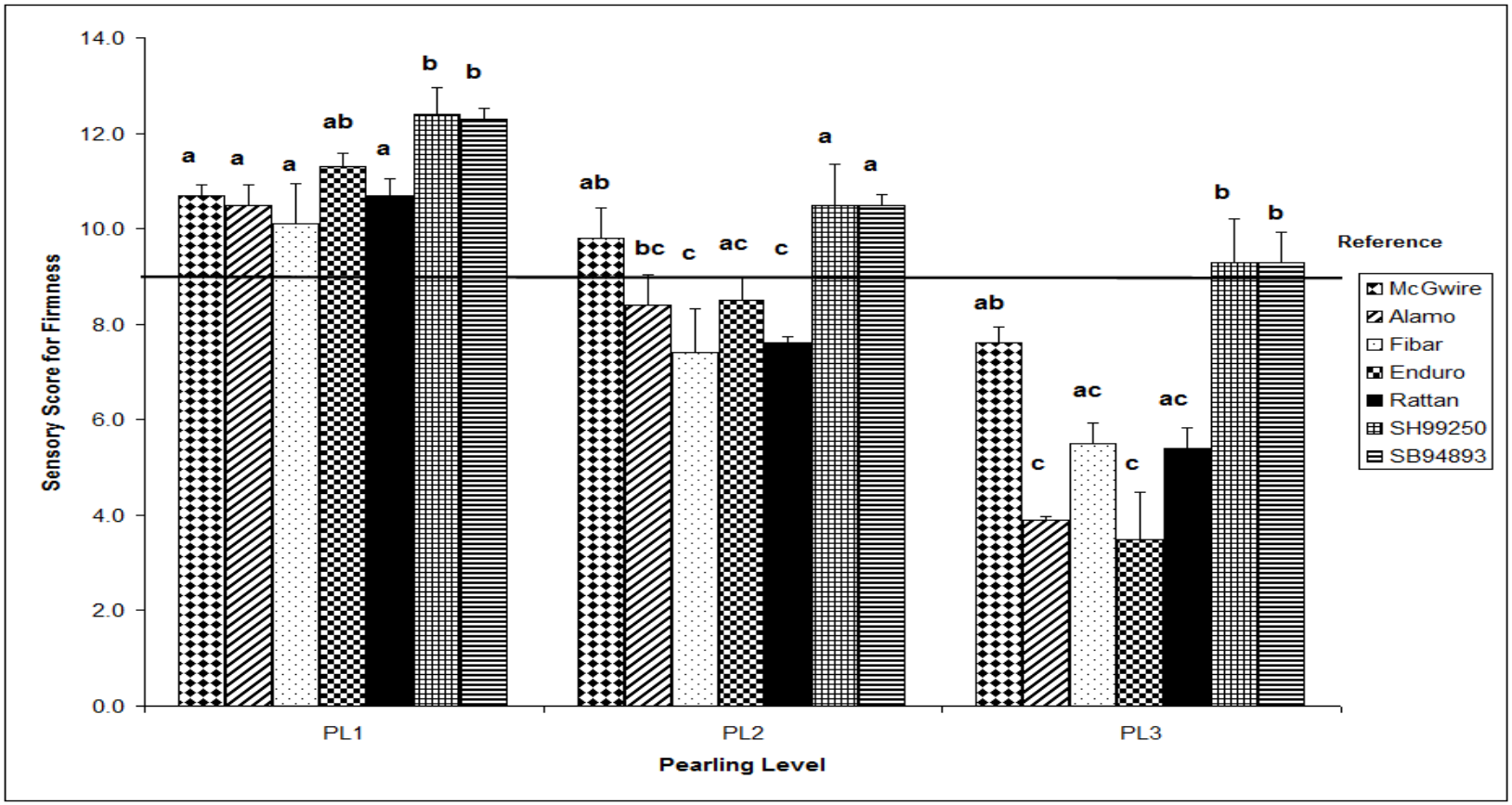
For all genotypes except HA starch genotype, SB94893, there was a significant decrease in flavor intensity between barley pearled at PL1 to those subjected to PL3 suggesting that components contributing to flavor are associated with the outer tissues of the barley kernel (Figure 4.48). No significant differences in flavor were found among genotypes at each PL (Figure 4.49).

Figure 4.46. Effect of pearling level within each genotype on mean sensory scores for firmness of selected Western Canadian barley varieties



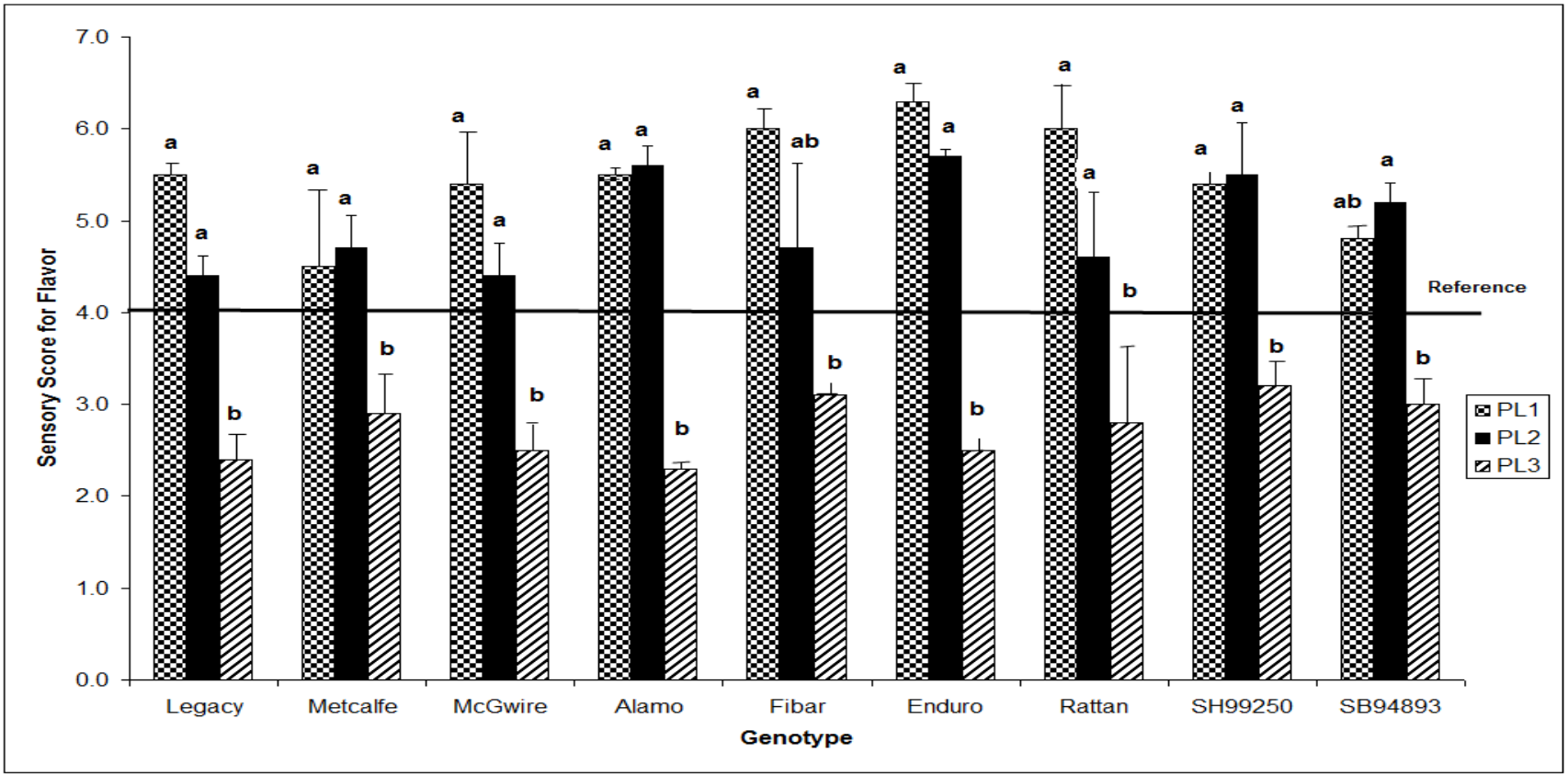
Different letters (a, b, c) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%
Reference was commercially pearled barley

Figure 4.47. Effect of genotype within each pearling level on mean sensory scores for firmness of selected Western Canadian hulless barley varieties



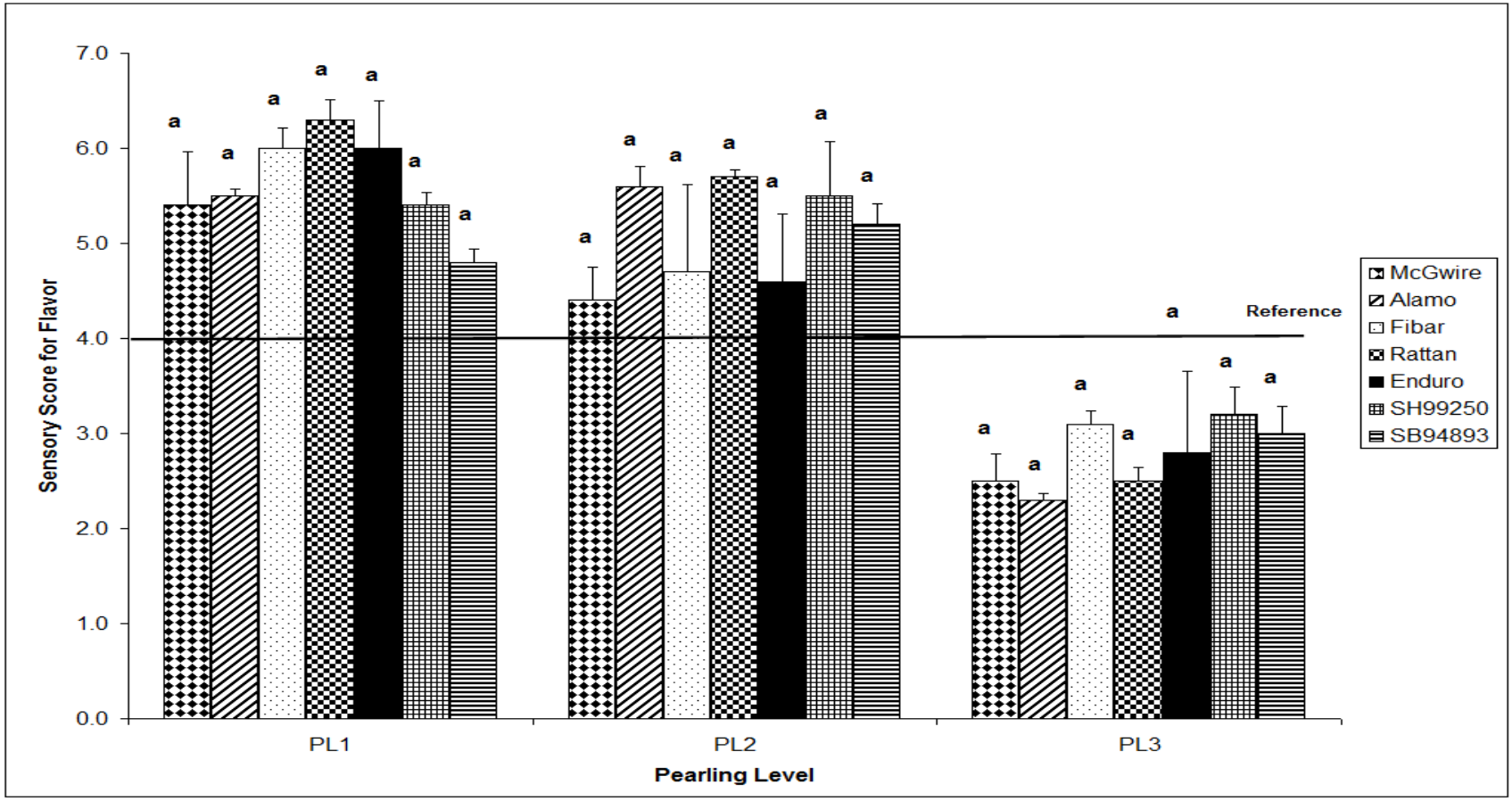
Different letters (a, b, c) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Reference was commercially pearled barley

Figure 4.48. Effect of pearling level within each genotype on mean sensory scores for flavor of selected Western Canadian barley varieties



Different letters (a, b) within the same genotype show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%
Reference was commercially pearled barley

Figure 4.49. Effect of genotype within each pearling level on mean sensory scores for flavor of selected Western Canadian hulless barley varieties



Different letters (a, b, c) within the same pearling level show significance (P≤0.05)
Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Reference was commercially pearled barley

5.0. CONCLUSIONS

5.1. Summary

Processing of barley is required to produce a product that is suitable for human consumption. Pearling is the most common processing method applied to barley since it is effective in removing the inedible hull, as well as contaminants, such as, microorganisms and chemical residues. Heavy levels of pearling (up to 45%) are used commercially to achieve a white colored, quick cooking product. However with consumers' greater acceptance of whole grain products, there is less demand to produce products that are white in color. In addition, the high processing losses associated with high levels of pearling can be minimized if lower levels of pearling are adopted. More importantly, reducing losses to the kernel will minimize the loss of nutrients resulting in a more nutritious product. The introduction of HB genotypes with modified starch properties offers the potential to produce pearled barley products with enhanced nutritional and functional properties. Few studies have been undertaken to examine the effects of light pearling on the compositional and technical properties of barley and very little information exists on the pearling properties of HB. Thus, this research was undertaken to determine the effect of PL and genotype on the physical grain characteristics, composition, and technological and sensory properties of selected varieties of Western Canadian barley.

Minimally pearled (PL1 and PL2) barley produced larger size kernels (length, width, and height) compared to heavily pearled (PL3) barley. During pearling, the outer tissues were removed from the major axis (length) and thickness (height) of the kernel rather than the minor axis (width). Higher processing yields (fewer broken kernels) were

achieved at lower levels of pearling (PL1 and PL2) compared to the highest level of pearling (PL3). This has considerable advantages for a food ingredient manufacturer since less processing achieves greater pearling yields thereby reducing costs. Lower levels of pearling resulted in barley that had a less bright appearance regardless if it was cooked or uncooked but this may not be a problem depending on the end use application.

Low levels of pearling yielded barley with higher levels of protein and free phenolic acids compared to more heavily pearled barley. Compared to heavily pearled cooked barley (PL3), minimally pearled cooked barley (PL1 & PL2) absorbed less water, was less bright, firmer, more intensely flavored, and contained less easily digestible starch.

As shown in the SEM micrographs, heavily pearled barley (PL3) resulted in complete removal of the pericarp, testa, aleurone, and subaleurone layers whereas, the minimally pearled barley (PL1 & PL2) resulted in removal of only the pericarp in PL1 and the pericarp, testa, and one or two aleurone layers in PL2. The term whole grain can only be applied to processed grains provided that the germ, endosperm, and bran are present in virtually the same proportion as the original grain before it was processed (Healthgrain Consortium, 2010). Removal of the very outer bran layer (up to 10% of the bran and 2% of the grain) is considered acceptable to minimize levels of undesirable substances such as bacteria, mold, agrochemicals, and heavy metals (Healthgrain Consortium, 2010). Thus, according to this definition, none of the pearling levels used in this study (PL1, PL2, or PL3) produced a processed grain that meets the definition of a whole grain since more than 2% of the grain was removed during pearling. However, as shown in the micrographs for minimally pearled barley (PL1 & PL2), the endosperm and

germ are still fully intact and the bran layer is only partially removed, thus most major anatomical components of the kernel remain. This finding suggests that the Healthgrain Consortium's definition for a whole grain may be too stringent for pearled barley and may warrant re-examination in light of the data obtained in this study.

Barley genotypes differing in hull characteristics but with normal starch characteristics were examined to determine if hulled barley differed significantly in physical grain characteristics, composition and technological and sensory properties. Once hulls were removed, normal starch hulled barley genotypes, Legacy & Metcalfe, and HB genotype McGwire were observed to be similar for the properties studied.

Comparison of HB genotypes differing in starch characteristics revealed significant differences for most properties examined. Waxy starch genotypes were smaller in size, had kernels that were less hard, and had a brighter appearance than normal and HA starch genotypes. However, the waxy starch genotype, Fibar, was an exception as it was found to be harder than other waxy genotypes, which is likely due to its higher β-glucan content. From a nutritional perspective, barley genotypes with modified starch properties are more attractive to food processors because of their higher β-glucan level compared to genotypes with normal starch characteristics. Waxy starch genotype, Fibar, and HA starch genotypes had significantly higher β-glucan levels compared to all other genotypes examined. Genotypes with high β-glucan levels may provide greater health benefits particularly as it relates to lowering cholesterol levels. Thus, the waxy starch genotype, Fibar, and HA starch genotypes have an advantage over other genotypes due to their high β-glucan content. Waxy starch genotypes exhibited higher β-glucan solubility when cooked compared to the HA starch genotype, SB94893,

thereby, waxy starch genotypes provide consumers with more soluble β-glucans than HA starch genotypes. Thus, the waxy starch genotype, Fibar, may have the most potential as a food ingredient from a nutritional standpoint. However, the low starch digestibility of HA starch genotypes offers other health benefits as it provides a lower glycemic response when consumed. The high level of amylose present in these genotypes is not as easily digested as amylopectin and blood sugar levels remain fairly steady. Thus, modified starch genotypes provide more health benefits than normal starch genotypes but whether waxy or HA starch characteristics are more beneficial depends on the consumer's desires.

Some food applications require firmer barley that holds its shape well (soups), whereas, others require softer, quicker cooking barley (porridge). After cooking, HA starch genotypes had higher firmness values and less water uptake than waxy starch genotypes. Thus, HA starch genotypes may be better suited for applications such as soups, whereas, waxy starch genotypes may be better suited for porridge.

PL and genotype significantly affected physical grain characteristics, composition, and technological and sensory properties of the barley examined in this study. HB genotypes show more promise for food use than hulled barley genotypes due to their higher β-glucan content. Genotypes showing the highest potential for food use are modified starch HB genotypes as they are superior in nutritional and functional aspects compared to normal starch HB genotypes. The waxy starch genotype Fibar, is exceptionally rich in soluble β-glucan fibre which gives it a nutritional advantage over other genotypes. Overall, the optimal amylopectin to amylose ratio of the selected HB genotype will depend on its intended end use and target market.

5.2. Strengths and limitations

This is the first study to examine the effects of PL on a broad range of attributes (physical grain characteristics, composition and technological and sensory properties) of several barley genotypes differing in hull and starch characteristics. This study is also one of very few studies to examine how low levels of pearling affect the barley kernel. Knowledge gained from this study will guide processors in the selection of pearling levels, as well as, genotypes for specific end use applications. It should be noted the barley genotypes chosen for examination in this study were some of the most recently released varieties and developed experimental lines which make this research pertinent since limited information is available on them.

The sample of Millhouse was a limitation in the study as it contained an uncharacteristically high percentage of adhering hulls. This affected its pearling properties and as a result, the data for this variety was excluded from the statistical analysis. The data collected for Millhouse is found in Appendix G. Ideally, it would have been preferable to have two HB genotypes with normal starch properties included in the study.

Another limitation to this study was the fact that barley samples were not all grown in the same location in a controlled field trial. It is well documented that growing location can affect grain properties. Thus, this work should be repeated on the same genotypes grown in controlled field trials in a number of locations over more than one crop year.

Lastly, although the sensory panel performed well in their assessment of the appearance, flavor and textural properties of the cooked barley, they were not adequately

trained to evaluate overall quality. Thus, the sensory data for overall quality was highly variable thereby limiting the value of the data.

5.3. Future research

A proper genotype by environment study should be conducted whereby barley genotypes are grown in controlled field plots in more than one location over several crop years. In particular, more research should be conducted on the waxy genotype, Fibar, based on its exceptionally high β-glucan content and solubility. To confirm findings regarding attribute differences in normal starch HB genotypes compared to modified starch HB genotypes, more than one normal starch variety should be studied. More work should be conducted to determine which levels of minimally pearled barley would be most acceptable to consumers. In addition, future studies could be undertaken to examine the effects of different processing methods on barley kernels especially heat treatments, such as micronization or superheated steam to increase starch and β-glucan digestibility and to decrease cook time.

A wide range of physical grain characteristics, composition, and technological and sensory properties were found among the various barley genotypes examined in this study. This provides food manufacturers with unlimited product opportunities that span a multitude of market sectors such as snack foods, pasta, breakfast cereals, beverages, and baked goods. In North America, the expanded use of barley in food products could fulfill governmental objectives to offer healthier food products to consumers and to utilize a domestically grown commodity. Thus, food scientists should undertake research to examine how minimally processed barley can be incorporated into new or existing food products.

5.4. Implications

Utilization of barley for human consumption in most developed countries is less than 5% of total production (Jadhav et al. 1998). It is hoped that this research will play a role in expanding the use of barley for human consumption by providing information on how the physical grain characteristics, composition, and technological and sensory properties of selected HB varieties grown in Western Canada are affected by levels of pearling. Knowledge gained from this study will guide food processors in the selection of barley genotypes based on hull and starch characteristics, as well as, pearling level depending on their end use application. Examination of the physical characteristics of the barley kernel after minimal pearling suggests the whole grain definition may require re-examination in light of the findings presented in this study. This is particularly important with the increasing prevalence of diseases like cardiovascular disease, diabetes, obesity, and cancer (Kalra, 2000; Anderson, 2002; McIntosh & Jacobs, 2002; Kim et al. 2006). Increased consumption of barley could play a role in prevention and management of these diseases especially if it was available in a less processed form.

The target market for minimally processed barley products encompasses the general population but especially those who are at risk for having cardiovascular disease, type 2 diabetes, gastrointestinal cancer, and/or are overweight or obese. Barley should be incorporated into nutritious products marketed specifically to these individuals. The high level of β-glucans found in barley is known to lower cholesterol levels(Behall et al. 2004) which would make it an ideal ingredient to incorporate into foods geared to those who are at risk of cardiovascular disease. Barley is a food with a low GI (<55), thus, it would be an optimal ingredient for individuals with type 2 diabetes to consume as it will not cause

a large glycemic response. Barley is high in antioxidants (eg. phenolic acids) (Slavin et al. 2000) and fibre (McIntosh & Jacobs, 2002) making it an excellent choice for cancer prevention. It can also be incorporated into weight management products (instant beverage mixes, nutritional bars, and capsules) due its ability to increase satiety through its high fibre and protein composition (Kim et al. 2006; Ludwig et al. 1999).

Value-added food products could be developed by incorporating lightly pearled HB with modified starch characteristics. Products such as porridge, soup, side dish mixes, sauces, energy bars, tapioca like puddings, or frozen meals are examples of products where lightly pearled barley could be added. It is also possible that a snack product could be developed by roasting lightly pearled barley. Increased awareness of how properties are affected by PL and genotype will increase demand for HB genotypes with modified starch characteristics and will in turn enable them to be more readily available to incorporate into food products.

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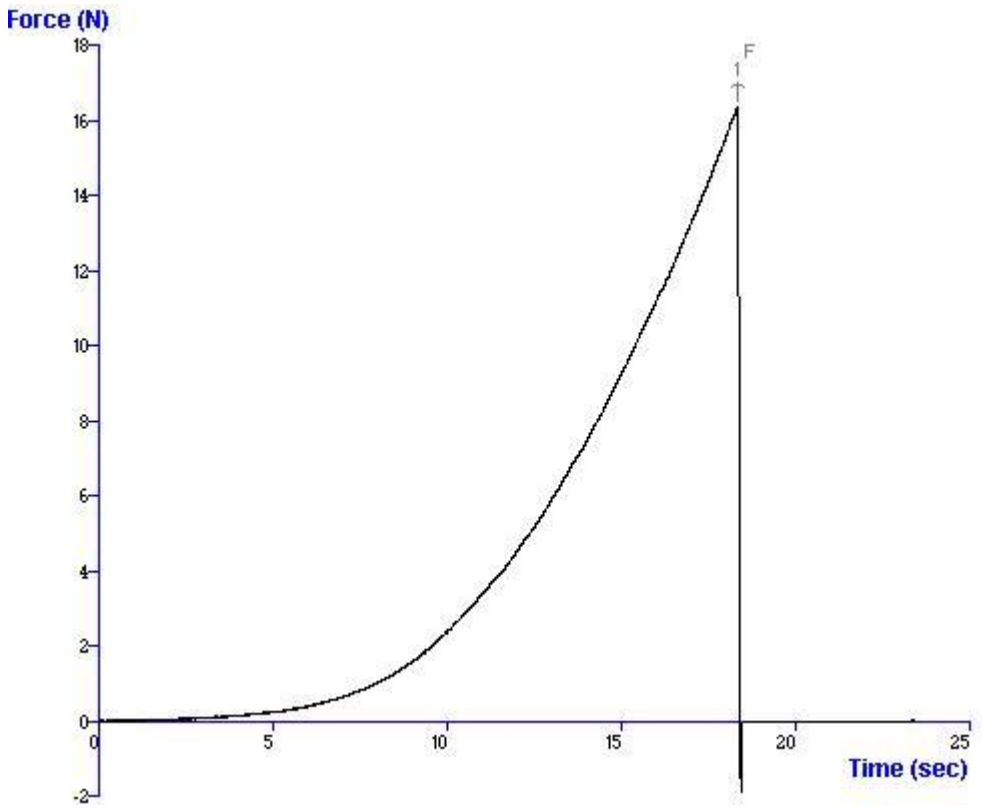
APPENDIX A

A Typical Peak Force Curve Using a TA-XT2 Texture Analyzer



TA-XT2 Settings

Mode: Force to compress barley kernel

Pre-test Speed: 10 mm/sec

Test Speed: 0.1 mm/sec

Post-test Speed: 10 mm/sec

Trigger Force: 0.05N

Distance: 50%

Load Cell: 30kg

Force: Newtons

APPENDIX B1

Letter of invitation to panelists for trained sensory panel

Canadian International Grains Institute
University of Manitoba
Department of Human Nutritional Sciences

June 23, 2008

Dear Fellow Colleague,

We are conducting a panel on pearled barley and invite you to participate. This letter explains what your commitment will be and the tasks involved.

If your schedule permits, you will be trained on how to evaluate the appearance, texture, and flavor properties of cooked, pearled barley. This will require 2 training sessions of 30 minutes each. Once training is completed, you will be asked to attend 12 test sessions of 30 minutes each.

The training will take place on Thursday, June 26th and Friday, June 27th from 11:30AM to 12:00PM in Classroom C (10th Floor, CIGI). The test sessions will be held twice a day on 3 days during the weeks of June 30th and July 7th. Exact dates and times will be determined during the training sessions.

As a token of our appreciation, you will receive a $50 Earl's gift certificate after completion of the study

If you are interested in taking part in this study, please reply to this message indicating your willingness to participate. Also if participating, please refrain from eating or drinking 30 minutes prior to the sensory evaluation session.

We hope that you will be able to participate and look forward to hearing from you.

Sincerely,

Lisa Humiski	Dr. Linda Malcolmson	Dr. Marta Izydorczyk
Graduate Student, MSc.	Co-Advisor	Co-Advisor

APPENDIX B2

Letter of consent for trained sensory panel

Canadian International Grains Institute
University of Manitoba
Department of Human Nutritional Sciences

Written Consent Form

Research Project Title: Sensory evaluation of barley
Researcher(s): Lisa Humiski, Dr. Linda Malcolmson, and Dr. Marta Izydorczyk

This consent form, a copy of which will be given to you for your records and reference, gives you the basic idea of what the research is about and what your participation will involve. Please take the time to read this carefully and feel free to ask any questions or express any concerns.

This study is being conducted to evaluate the appearance, texture, and flavor attributes of cooked, pearled barley. Two training sessions will be held where panelists will meet as a group to become familiar with the attributes associated with barley, as well as, with the line scale used to measure the intensity of the attributes. Barley with a range of intensities for various attributes will be evaluated to familiarize panelists with the product. Twelve test sessions will then be held twice a day on six separate days.

Panelists will be identified by number and all results obtained will be kept confidential. Access to information linking panelist to number will be limited strictly to the principal researcher named above. Data published will be presented as group means with no individual names given.

A $50 gift certificate for Earl's restaurant will be given to panelists who complete all of the required training and test sessions. Also, you will receive a copy of the purpose of the study, as well as, the results within three weeks after the study is completed.

Your signature on this form indicates that you have understood the information regarding your participation in this research project and agree to participate. You are free to withdraw from the study at any time without prejudice.

_____ _____
Participant's Signature Date

_____ _____
Researcher's Signature Date

APPENDIX B3

Sensory ballot used by trained panel

Name: _____

Sensory Evaluation of Pearled Barley

For each of the following attributes, rate the intensity of each coded sample in relation to the reference by placing a vertical line accompanied by the corresponding code number on the scale provided.

Please rate samples in order provided: _____ _____ _____ _____ _____

BRIGHTNESS: Rate the degree of brightness of the barley kernels.

Dark Light

KERNEL TO KERNEL ADHESION: Rate the degree to which the barley kernels adhere to one another by visual examination.

- A **low degree** is characterized by kernels that have a low adherence to each other and do not form a tight mass.
- A **high degree** is characterized by kernels that have a high adherence to each other and form a tight mass.

Low degree High degree

FIRMNESS: Rate the amount of force required to bite through 4 barley kernels placed between your molar teeth.

Soft Firm

FLAVOR: Rate the intensity of overall flavor after chewing and swallowing 4 barley kernels.

Bland Intense

OVERALL QUALITY: Rate the overall quality of the sample.

Poor High

For each sample, state why you rated the sample the way you did.

APPENDIX C

Analysis of variance results for physical grain characteristics, composition, and technological and sensory properties of selected Western Canadian barley varieties

Table 1. Analysis of variance results for the shape and size of selected Western Canadian barley varieties.

		Length			Width			Height		
Source	**df**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**
Model	35	2	277	**<0.0001**	0	47	**<0.0001**	0	28	**<0.0001**
Genotype (G)	8	1	237	**<0.0001**	0	165	**<0.0001**	0	15	**<0.0001**
Pearling Level (PL)	3	13	2278	**<0.0001**	0	60	**<0.0001**	2	267	**<0.0001**
G x PL	24	0	40	**<0.0001**	0	6	**<0.0001**	0	2	**<0.0001**
Error	36	0			0			0		

Table 2. Analysis of variance results for brightness (L*) of selected Western Canadian barley varieties

		Brightness		
Source	**df**	**MS**	**F**	**Pr > F**
Model	35	102	777	**<0.0001**
Genotype (G)	8	68	514	**<0.0001**
Pearling Level (PL)	3	958	7255	**<0.0001**
G x PL	24	7	54	**<0.0001**
Error	36	0		

Table 3. Analysis of variance results for starch, protein, and ash concentration of selected Western Canadian barley varieties

		Starch			Protein			Ash		
Source	**Df**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**
Model	35	67	71	**<0.0001**	15	10232	**<0.0001**	0	3550	**<0.0001**
Genotype (G)	8	161	169	**<0.0001**	47	31761	**<0.0001**	0	1881	**<0.0001**
Pearling Level (PL)	3	330	346	**<0.0001**	47	32193	**<0.0001**	4	34133	**<0.0001**
G x PL	24	3	3	**<0.0001**	0	310	**<0.0001**	0	284	**<0.0001**
Error	36	1			0			0		

Table 4. Analysis of variance results for β-glucan, arabinoxylan, and free phenolic acid concentration of selected Western Canadian barley varieties

		β-glucan			Arabinoxylans			Phenolic acids[a]		
Source	**df**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**
Model	35	7	650	**<0.0001**	3	160	**<0.0001**	1	384	**<0.0001**
Genotype (G)	8	30	2759	**<0.0001**	3	133	**<0.0001**	1	310	**<0.0001**
Pearling Level (PL)	3	2	170	**<0.0001**	24	1289	**<0.0001**	7	3573	**<0.0001**
G x PL	24	0	7	**<0.0001**	1	28	**<0.0001**	0	10	**<0.0001**
Error	36	0						0		

[a]Phenolic acid concentration in acidified methanol extract

Table 5. Analysis of variance results for β-glucan solubility of uncooked and cooked varieties of Western Canadian barley

		Uncooked barley			Cooked barley		
Source	**df**	**MS**	**F-value**	**Pr > F**	**MS**	**F-value**	**Pr > F**
Model	19	71	402	**<0.0001**	263	4555	**<0.0001**
Genotype (G)	4	247	1403	**<0.0001**	1067	18484	**<0.0001**
Pearling Level (PL)	3	96	543	**<0.0001**	27	465	**<0.0001**
G x PL	12	6	34	**<0.0001**	54	935	**<0.0001**
Error	20	0			0		

Table 6. Analysis of variance results for *in vitro* starch digestibility of selected varieties of Western Canadian barley digested for 30 min

		***In vitro* Starch Digestibility**		
Source	**df**	**MS**	**F**	**Pr > F**
Model	14	19	20	**<0.0001**
Genotype (G)	4	37	39	**<0.0001**
Pearling Level (PL)	2	56	59	**<0.0001**
G x PL	8	1	1	**0.5071**
Error	15	1		

Table 7. Analysis of variance results for brightness, kernel to kernel adhesion, and firmness of selected Western Canadian barley varieties as determined by trained sensory panel[a]

		Brightness			Kernel to Kernel Adhesion			Firmness		
Source	**df**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**
Model	33	147	106	**<0.0001**	77	18	**<0.0001**	93	34	**<0.0001**
Panelist	7	11	8	**<0.0001**	34	8	**<0.0001**	25	9	**<0.0001**
Genotype (G)	8	16	12	**<0.0001**	128	29	**<0.0001**	80	29	**<0.0001**
Pearling Level (PL)	2	2262	1630	**<0.0001**	257	59	**<0.0001**	978	356	**<0.0001**
G x PL	16	8	6	**<0.0001**	48	11	**<0.0001**	19	7	**<0.0001**
Error	34	1			4			3		

[a] n=8 panelists

Table 8. Analysis of variance results for flavor and overall quality of selected Western Canadian barley varieties as determined by trained sensory panel[a]

		Flavor			Overall Quality		
Source	**df**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**
Model	33	34	13	**<0.0001**	44	6.03	**<0.0001**
Panelist	7	59	23	**0.1330**	118	16.39	**<0.0001**
Genotype (G)	8	4	2	**<0.0001**	25	3.50	**<0.0006**
Pearling Level (PL)	2	303	118	**<0.0001**	71	9.79	**<0.0001**
G x PL	16	4	1	**0.1171**	17	2.30	**<0.0031**
Error	34						

[a] n=8 panelists

APPENDIX D1

Significance values[a] showing effect of pearling level within genotype for physical grain characteristics, composition, and technological and sensory properties of selected varieties of Western Canadian barley

	P-value			
	Legacy	**Metcalfe**	**McGwire**	**Alamo**
PHYSICAL				
Length (mm)	0.000	0.000	0.000	0.000
Width (mm)	0.000	0.000	0.013	0.000
Height (mm)	0.000	0.000	0.000	0.000
Hardness	0.124	0.127	0.026	0.044
Brightness (L*)	0.000	0.000	0.000	0.000
COMPOSITION				
Starch (%)	0.000	0.000	0.002	0.000
Protein (%)	0.000	0.000	0.000	0.000
Ash (%)	0.000	0.000	0.000	0.000
β-glucan (%)	0.021	0.003	0.004	0.003
Arabinoxylan (%)	0.000	0.000	0.000	0.000
Free phenolic acids (μg/mg)	0.000	0.000	0.000	0.000
COOKED[b]				
Brightness (L*)	0.000	0.000	0.000	0.000
Firmness (N)	0.000	0.000	0.000	0.000
Water uptake (g/100g)	0.000	0.000	0.000	0.000
β-glucan solubility (%)	0.000		0.000	
In vitro starch digestibility (%)	0.005		0.009	
SENSORY				
Brightness	0.000	0.000	0.000	0.000
Kernel to kernel adhesion	0.000	0.000	0.039	0.002
Firmness	0.000	0.000	0.000	0.000
Flavor	0.000	0.034	0.000	0.000
Overall quality	0.108	0.121	0.235	0.003

[a] Significant at P≥0.05
[b] Cooked for 30 min

APPENDIX D1

Significance values[a] showing effect of pearling level within genotype for physical grain characteristics, composition, and technological and sensory properties of selected varieties of Western Canadian barley

	P-value				
	Fibar	**Enduro**	**Rattan**	**SH99250**	**SB94893**
PHYSICAL					
Length (mm)	0.000	0.000	0.000	0.000	0.000
Width (mm)	0.000	0.000	0.000	0.000	0.000
Height (mm)	0.000	0.000	0.000	0.000	0.000
Hardness	0.009	0.013	0.107	0.001	0.001
Brightness (L*)	0.000	0.000	0.000	0.000	0.000
COMPOSITION					
Starch (%)	0.002	0.023	0.006	0.004	0.000
Protein (%)	0.000	0.000	0.000	0.000	0.000
Ash (%)	0.000	0.000	0.000	0.000	0.000
β-glucan (%)	0.007	0.003	0.001	0.000	0.032
Arabinoxylan (%)	0.000	0.000	0.000	0.000	0.000
Free phenolic acids (μg/mg)	0.000	0.000	0.000	0.000	0.000
COOKED[b]					
Brightness (L*)	0.000	0.000	0.000	0.000	0.000
Firmness (N)	0.000	0.000	0.000	0.001	0.000
Water uptake (g/100g)	0.000	0.000	0.000	0.000	0.000
β-glucan solubility (%)	0.000		0.000		0.000
In vitro starch digestibility (%)	0.151		0.048		0.056
SENSORY					
Brightness	0.000	0.000	0.000	0.000	0.000
Kernel to kernel adhesion	0.232	0.000	0.026	0.006	0.073
Firmness	0.000	0.000	0.000	0.000	0.000
Flavor	0.001	0.000	0.000	0.003	0.010
Overall quality	0.045	0.340	0.275	0.314	0.096

[a] Significant at P≥0.05

[b] Cooked for 30 min

APPENDIX D2

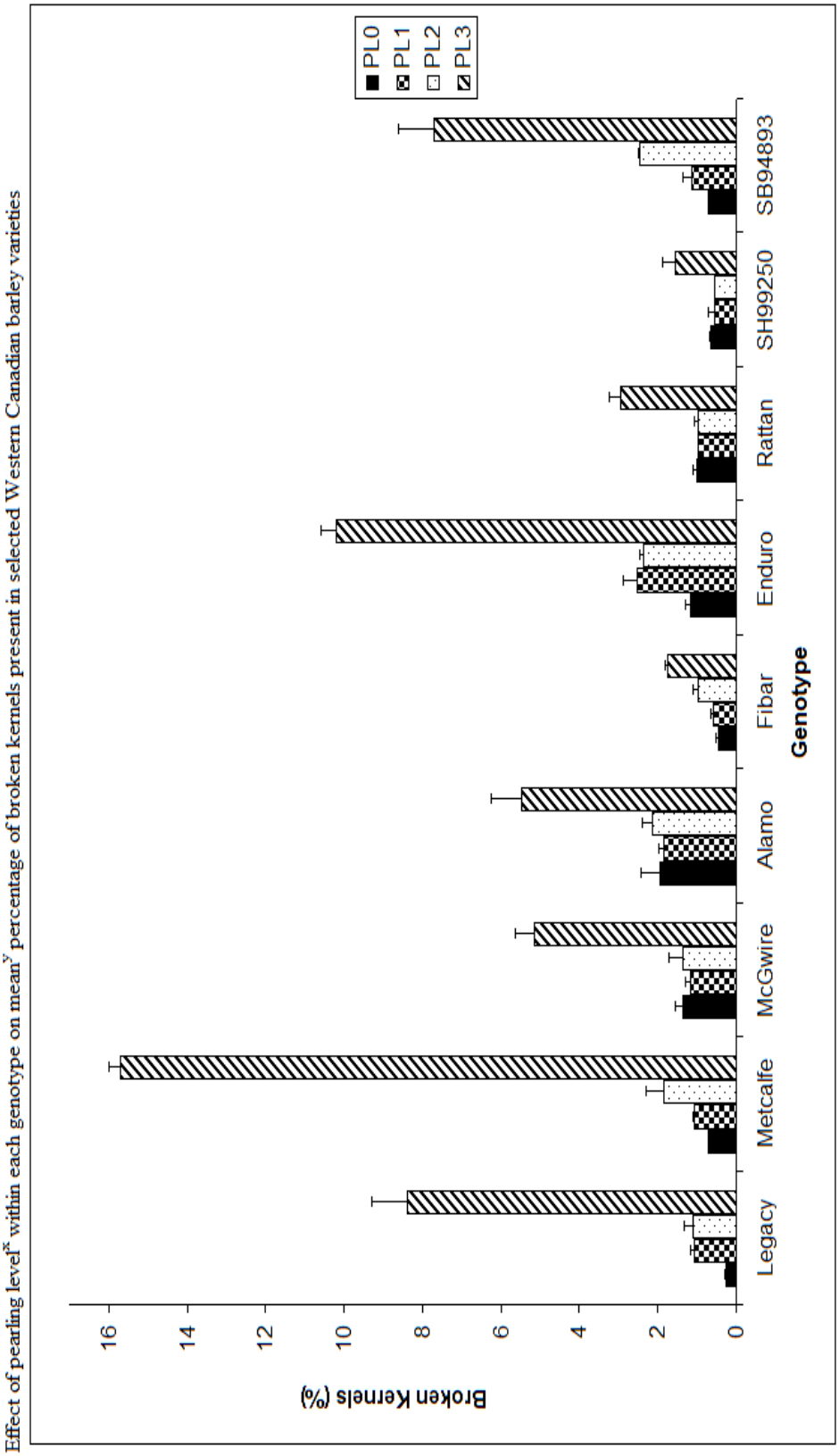
Significance values[a] showing effect of genotype within pearling level for physical grain characteristics, composition, and technological and sensory properties of selected hulless varieties of Western Canadian barley

	P-value			
	PL0	**PL1**	**PL2**	**PL3**
PHYSICAL				
Length (mm)	0.000	0.000	0.000	0.000
Width (mm)	0.000	0.000	0.000	0.000
Height (mm)	0.061	0.003	0.001	0.003
Hardness	0.000	0.000	0.000	0.000
Brightness (L*)	0.000	0.000	0.000	0.000
COMPOSITION				
Starch (%)	0.000	0.000	0.000	0.000
Protein (%)	0.000	0.000	0.000	0.000
Ash (%)	0.000	0.000	0.000	0.000
β-glucan (%)	0.000	0.000	0.000	0.000
Arabinoxylan (%)	0.000	0.000	0.000	0.000
Phenolic acids (μg/mg)	0.000	0.000	0.000	0.000
COOKED[b]				
Brightness (L*)	0.000	0.001	0.026	0.001
Firmness (N)	0.000	0.000	0.000	0.000
Water uptake (g/100g)	0.016	0.000	0.000	0.000
β-glucan solubility (%)	0.000	0.000	0.000	0.000
In vitro starch digestibility (%)	N/A	0.007	0.001	0.020
SENSORY				
Brightness	N/A	0.001	0.000	0.000
Kernel to kernel adhesion	N/A	0.000	0.000	0.000
Firmness	N/A	0.000	0.000	0.000
Flavor	N/A	0.441	0.396	0.458
Overall quality	N/A	0.611	0.161	0.018

[a] Significant at P≥0.05

[b] Cooked for 30 min

APPENDIX E



Effect of pearling level[x] within each genotype on mean[y] percentage of broken kernels present in selected Western Canadian barley varieties

[x] Level of outer layers removed for HB samples; PL0- unpearled, PL1- 5%, PL2- 10%, PL3- 25%
Level of outer layers removed for hulled barley samples; PL0- unpearled, PL1- 10%, PL2- 15%, PL3- 30%

[y] Mean; n=2

APPENDIX F

Analysis of variance results for brightness, firmness, and water uptake of selected Western Canadian barley varieties cooked for differing lengths of time

Table 1. Analysis of variance results for brightness of selected Western Canadian barley varieties cooked for differing lengths of time

		20 min			30 min			40 min		
Source	**df**	**MS**	**F**	**Pr>F**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**
Model	35	57	210	**<0.0001**	67	444	**<0.0001**	66	239	**<0.0001**
Genotype (G)	8	7	27	**<0.0001**	5	31	**<0.0001**	5	20	**<0.0001**
Pearling Level (PL)	3	637	2323	**<0.0001**	745	4955	**<0.0001**	728	2628	**<0.0001**
G x PL	24	2	8	**<0.0001**	3	18	**<0.0001**	4	13	**<0.0001**
Error	36	0.3			0.2			0.3		

Table 2. Analysis of variance results for firmness of selected Western Canadian barley varieties cooked for differing lengths of time

		20 min			30 min			40 min		
Source	**df**	**MS**	**F**	**Pr>F**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**
Model	35	8899	204	**<0.0001**	4338	140	**<0.0001**	2603	34	**<0.0001**
Genotype (G)	8	2715	62	**<0.0001**	3047	98	**<0.0001**	2316	30	**<0.0001**
Pearling Level (PL)	3	93883	2149	**<0.0001**	40169	129 6	**<0.0001**	21856	286	**<0.0001**
G x PL	24	337	8	**<0.0001**	290	9	**<0.0001**	292	4	**<0.0001**
Error	36	44						77		

Table 3. Analysis of variance results for water uptake of selected Western Canadian barley varieties cooked for differing lengths of time

		20 min			30 min			40 min		
Source	**df**	**MS**	**F**	**Pr>F**	**MS**	**F**	**Pr > F**	**MS**	**F**	**Pr > F**
Model	35	2757	205	**<0.0001**	5251	288	**<0.0001**	7070	514	**<0.0001**
Genotype (G)	8	9756	73	**<0.0001**	1532	84	**<0.0001**	2159	157	**<0.0001**
Pearling Level (PL)	3	2822 9	210 0	**<0.0001**	53790	2950	**<0.0001**	72078	5240	**<0.0001**
G x PL	24	166	12	**<0.0001**	423	23	**<0.0001**	582	42	**<0.0001**
Error	36	13			18			14		

APPENDIX G

Physical grain characteristics, composition, and technological and sensory property results for barley variety, Millhouse (hulless, normal starch)

PROPERTIES	**PEARLING LEVEL (PL)**			
	PL0	**PL1**	**PL2**	**PL3**
PHYSICAL				
Width (mm)	3.28 ± 0.03	3.19 ± 0.02	3.10 ± 0.08	3.15 ± 0.00
Length (mm)	10.05 ± 0.20	8.39 ± 0.01	7.47 ± 0.11	6.68 ± 0.02
Hardness	60.50 ± 18.02	60.33 ± 20.52	62.87 ± 19.31	72.35 ± 19.53
Brightness (L*)	58.99 ± 0.11	60.04 ± 0.02	58.80 ± 0.01	66.85 ± 0.58
Sound kernel ratio (%)	49.50 ± 0.07	99.40 ± 0.12	99.30 ± 0.02	96.80 ± 0.09
Pearl time (sec)	0	20 - 27	22 - 39	360 - 380
COMPOSITION				
Starch (%)	52.89 ± 0.45	56.86 ± 0.33	60.56 ± 0.26	68.11 ± 0.10
Protein (%)	17.09 ± 0.38	17.71 ± 0.50	17.62 ± 0.26	16.79 ± 0.01
Ash (%)	2.68 ± 0.21	2.52 ± 0.04	2.21 ± 0.20	1.54 ± 0.14
β-glucan (%)	4.07 ± 0.04	4.32 ± 0.03	4.51 ± 0.04	4.68 ± 0.00
Arabinoxylan (%)	6.78 ± 0.05	4.20 ± 0.54	4.16 ± 0.20	2.68 ± 0.10
Phenolic acids (μg/mg)	3.51 ± 0.03	3.50 ± 0.13	3.35 ± 0.02	2.49 ± 0.01
TECHNOLOGICAL				
Brightness (L*)	45.69 ± 0.19	52.06 ± 0.18	54.91 ± 0.25	64.20 ± 0.21
Firmness (N)	101.25 ± 21.1	69.34 ± 2.3	67.20 ± 4.4	43.99 ± 2.5
Water uptake (g/100g)	142.98 ± 0.27	136.12 ± 1.33	126.63 ± 4.04	192.40 ± 0.57
SENSORY (1-9 scale)				
Brightness	*	*	*	7.5 ± 0.07
Kernel to kernel adhesion	*	*	*	6.0 ± 1.49
Firmness	*	*	*	9.5 ± 0.00
Flavor	*	*	*	4.6 ± 0.35
Overall quality	*	*	*	7.0 ± 1.06