Quality Characteristics of Fresh and Dried White Salted Noodles Enriched with Flour from Hull-less Barley Genotypes of Diverse Amylose Content

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ABSTRACT

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Fresh and dried white salted noodles (WSN) were prepared by incorporating up to 40% flour from hull-less barley (HB) genotypes with normal amylose, waxy, zero amylose waxy (ZAW), and high amylose (HA) starch into a 60% extraction Canada Prairie Spring White (cv. AC Vista) wheat flour. The HB flours, depending on genotype, contained four to six times the concentration of β-glucan of the wheat flour, offering potential health benefits. The HB-enriched noodles were made with conventional equipment without difficulty. Noodles containing 40% HB flour required less work input during sheeting, probably due to higher optimum water absorption and weakening of the dough due to dilution of wheat gluten. The addition of HB flour had a negative impact on WSN color and appearance, as evident from decreased brightness, increased redness, and more visible specking. The impact of HB flour on cooked WSN texture varied by starch type. Enrichment with HA or normal starch HB flour produced WSN with bite and chewiness values equivalent to or superior to the wheat flour control. Addition of waxy and ZAW HB flour resulted in WSN with lower values for bite and chewiness. The diversity of HB starch types allows tailoring of WSN texture to satisfy specific markets. HB flour also has potential as an ingredient in novel noodle products targeting health-conscious consumers who associate darker colored cereal-based foods with superior nutritional composition.

Barley has a long history of food use. In modern times, consumption of barley-based foods decreased but interest is reviving due to the presence of constituents in barley known to prevent and to alleviate certain diseases (Jadhav et al 1998; Slavin et al 2000). Differences exist in the chemical composition of hulled and hull-less (HB) barley, with HB displaying better nutritional potential for incorporation into human foods. HB is rich in dietary fiber (10–20%) and contains functional components that lower blood cholesterol, reduce the risk of coronary heart disease, control blood glucose levels, and reduce the risk of colon cancer (Newman and Newman 1991; Jenkins et al 1995; Yokoyama et al 1997). Barley is also an excellent source of B-complex vitamins, is rich in minerals (Jadhav et al 1998), and has beneficial antioxidant properties (Burton and Traber 1990; Slavin et al 2000). The starch amylose-to-amylopectin ratio of barley genotypes varies from zero amylose waxy (ZAW) to high amylose (HA), influencing composition and functionality of this grain as a food ingredient. Xue et al (1997) found that HB had greater concentrations of digestible nutrients than hulled barley, and waxy and HA genotypes consistently had higher β-glucan levels than normal amylose starch types.

The barley kernel has localized concentrations of components, lending it to fractionation into products of variable composition, some with elevated levels of nutritionally beneficial components (Izydorczyk et al 2002). Roller milling of HB yields fractions rich in arabinoxylans, β-glucans, flavanoids, tocopherol, and tocotrienol (Andersson et al 2003). HB flour is lower in nutritionally beneficial components than other HB roller milling products such as bran or fiber-rich fractions enriched in the endosperm cell walls, but still contains significantly higher levels of β-glucan than wheat flour (Izydorczyk et al 2003).

HB flour has been incorporated successfully into muffins, pancakes, and biscuits (Berglund et al 1992) and into chapattis (Sidhu et al 1990). Klamczynski and Czuchajowska (1999) reported that the incorporation of 20% waxy or nonwaxy barley flour did not significantly affect bread loaf volume and yielded a slightly softer texture. In contrast, Gill et al (2002a,b) found that substitution of 15% waxy barley flour in bread lowered loaf volume and altered crumb characteristics; normal amylose barley flour imparted lesser effects. Trogh et al (2004) reported that addition of xylanase to the formula of HB flour-enriched bread gave bread of improved palatability and higher loaf volume. Dexter et al (2005a) reported that satisfactory sponge-and-dough bread could be attained when wheat flour was enriched with a fiber-rich fraction from HB barley.

Barley fractions have also been incorporated into pasta and noodles (Cheigh et al 1976; Ryu et al 1977; Knuckles et al 1997; Marconi et al 2000; Dexter et al 2005b; Hatcher et al 2005; Izydorczyk et al 2005). The tendency for barley fractions to impart a darker grey color (Quinde et al 2004) is a potential deterrent to consumer acceptability of barley-enriched pasta and noodles because color and appearance are important aesthetic features for both foods. Dexter et al (2005b) found that pasta color deteriorated when durum wheat semolina was enriched with HB roller milling fractions. Hatcher et al (2005) reported that the color of yellow alkaline noodles (YAN) deteriorated with more visible specks present when enriched with up to 40% HB flour. The color and speckiness of both YAN and white salted noodles (WSN) were also adversely affected when enriched with a HB fiber-rich fraction (Izydorczyk et al 2005). These color defects may deter acceptance by traditional pasta and noodle consumers, but product color and appearance was judged, in all cases, to be adequate for acceptance by health conscious consumers.

The color defects of HB-enriched pasta and Asian noodles are mitigated by the textural properties. Dexter et al (2005b) found that for pasta enriched with HB flour and fiber-rich fractions, texture was acceptable except when low-amylose starch HB flour was used. Similarly, Izydorczyk et al (2005) reported improved or acceptable cooking quality when HB fiber-rich fractions were incorporated into YAN and WSN. Hatcher et al (2005) found that texture modification of YAN enriched with HB flour was related to HB starch type; YAN chewiness decreased with addition of waxy and ZAW HB flour, but increased with addition of normal amylose and HA HB flour. Baik and Czuchajowska (1997) reported that introducing 15% waxy barley flour into Japanese udon noodles also altered texture: texture profile analysis (TPA) hardness, cohesiveness, springiness, gumminess, and chewiness decreased. For Japanese udon noodles, where soft texture is generally preferred, those texture changes would not necessarily be disadvantageous (Nagao 1996). The objective of this study was to

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determine the effects of incorporating HB flour derived from HB genotypes with elevated β-glucan and varying levels of starch amylose into fresh and dried WSN.

MATERIALS AND METHODS

Materials

The HB flours used in this study have previously been reported in detail (Hatcher et al 2005). For convenience, the properties most relevant to this study are summarized in Table I.

WSN Noodle Preparation

HB flour was incorporated at 20% and 40% replacement levels for wheat flour before processing. An optimum crumb water absorption of 37% was determined for 100% wheat flour and for WSN enriched with 20% HB flour based on dough crumble aggregate particle size, consistency, and crumb feel. A higher absorption level (42%) was required for the WSN enriched with 40% HB flour. No differences among various barley cultivars were observed.

The appropriate amount of a 1% w/w salt (NaCl) solution was added to flour during a 5-min mixing regime using a commerical mixer (N50, Hobart Canada, North York, ON) as per Kruger et al (1994). The moist crumbly aggregate mixture was fed between temperature controlled rollers (28°C) of a laboratory noodle machine (Ohtake, Tokyo, Japan) with an initial gap setting of 3 mm. The resulting sheet was folded once and again passed through the rollers to simulate the lamination step in industrial plants. The noodle sheet was cut into a representative section 25 cm long and underwent seven successive reduction passes within 4.5 min, ending with a final gap width of 1.1 mm. Work requirements during processing were determined as per Hatcher et al (1999).

The resulting noodle sheet was cut into three sections, with the two smaller portions held at ambient temperature in sealed plastic containers for color and image analysis, respectively. The remaining noodle sheet was cut into strands using a No. 22 cutter, with a portion placed in sealed plastic containers at ambient room temperature (≈21°C) for 1 hr before cooking. The remaining fresh WSN strands were placed on wooden dowels and dried over a 16-hr period in a drying cabinet (Conviron, Winnipeg, Canada) using the temperature/relative humidity profiles of 25°C/55% rh (1 hr), 25°C/90% rh (7.5 hr), 35°C/90% rh (5.5 hr), 25°C/70% rh (2 hr). The aforementioned drying cycle was adopted for routine quality assessment at the Grain Research Laboratory on the basis of the proven ability to produce flexible dried noodles with consistently good breaking strength (Kruger et al 1995). The dried noodles were placed in nonsealed plastic bags and allowed to cure and equilibrate to atmospheric conditions for a minimum of two weeks at ambient room temperature before further analysis.

Noodle Color and Appearance

Color of raw fresh WSN and uncooked dried WSN was evaluated with a spectrocolorimeter (Labscan II, HunterLab, Reston, VA) equipped with a D65 illuminant using the CIE 1976 *L**, *a**, and *b** color scale. Color of raw fresh WSN was determined 0, 1, 2, and 24 hr after processing. Samples were enclosed in a black plastic container to eliminate ambient light effects. Raw noodle sheets were folded twice to provide three layers of thickness for measurement before enclosing. Three measurements were taken at two different locations on the dough sheet and the readings were averaged. Multilayers of dried noodles were placed directly over the light source before enclosing in the black plastic container. Samples were presented three times and results were averaged.

Images of raw noodle sheets (25 cm^2) were captured at 1, 2, and 24 hr after processing using a commercial scanner (model 3, Microteck, Canada) and analyzed for specks using software developed in-house based on KS-400 software (Carl Zeiss Vision, Echting, Germany) as per Hatcher et al (2005).

Noodle Optimum Cook Time

Optimum cook time was determined by removing subsamples during cooking at 30-sec intervals, placing them in temperature controlled (20°C) water, and squeezing them between plexiglass plates to observe the inner core. Noodles were considered opti-

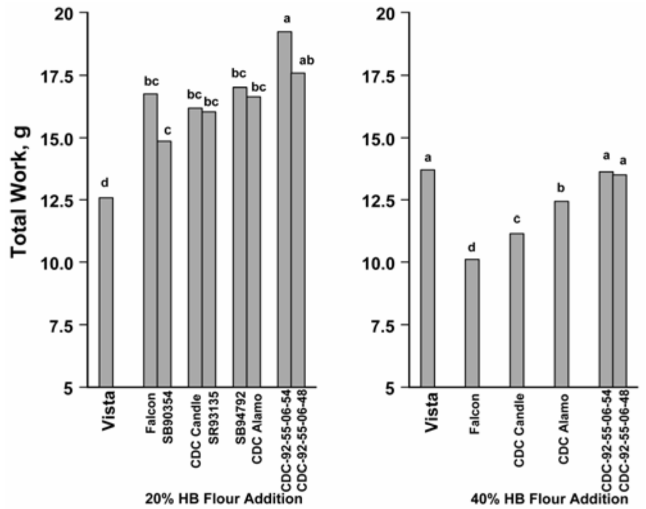

Fig. 1. Energy requirements during processing of white salted noodles with addition of hull-less barley flour compared with Vista wheat flour. Different letters above each group indicate significant difference ($P < 0.05$).

TABLE I
Sample Characterization of Hull-less Barley and Wheat Flour[a,b]

Cultivar	Starch Type	Color			Starch Amylose (%)	PPO Activity (nmoles O_2/g/min)	POD Activity (pyrogallol units/g/min)	β-Glucans (%)	Arabinoxylans (%)
		*L**	*a**	*b**					
Hull-less barley									
Falcon	Normal	93.2	–0.47	6.79	23.8	84	387	3.48	1.38
SB90354	Normal	93.2	–0.22	5.83	24.3	94	489	3.94	1.37
CDC Candle	Waxy	93.3	–0.45	5.72	4.3	118	307	3.96	0.90
SR93135	Waxy	93.3	–0.69	7.26	4.8	64	263	4.37	0.81
SB94792	Zero amylose waxy	93.4	–0.59	6.89	0	50	433	3.97	1.00
CDC Alamo	Zero amylose waxy	93.1	–0.39	6.45	0	138	358	4.23	1.10
CDC-92-55-06-54	High amylose	92.8	–0.28	5.32	41.4	36	306	3.93	1.60
CDC-92-55-06-48	High amylose	92.8	–0.14	4.81	41.8	19	257	4.06	1.82
Wheat									
AC Vista	Normal	92.7	–0.72	9.01	nd	17	171	0.72	1.69

[a] Analytical values are expressed on a dry matter basis.

[b] Adapted from Hatcher et al (2005).

mally cooked once the white inner core of four out of five noodle subsamples disappeared, indicating that cooking water had fully penetrated to the core.

Cooked Noodle Texture

Noodles (25 g) were cooked to optimum time in 400 mL of boiling distilled water 1 hr after completion of processing. The cooked noodles were drained, rinsed for 1 min with distilled water (20°C), shaken to release any free water, and placed in sealed plastic containers. All texture tests were performed on five sets of three noodle strands. The maximum cutting stress (MCS) test (Oh et al 1983) was performed 10 min after rinsing and shaking. Compression (Oh et al 1983) and texture profile analysis (TPA) (Bourne 1976, 1978) were performed at 8 and 16 min after commencement of the cutting stress test, respectively, to achieve minimum variability in test results. Texture measurements were performed using a texture analyzer (TA-XT2i, Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK).

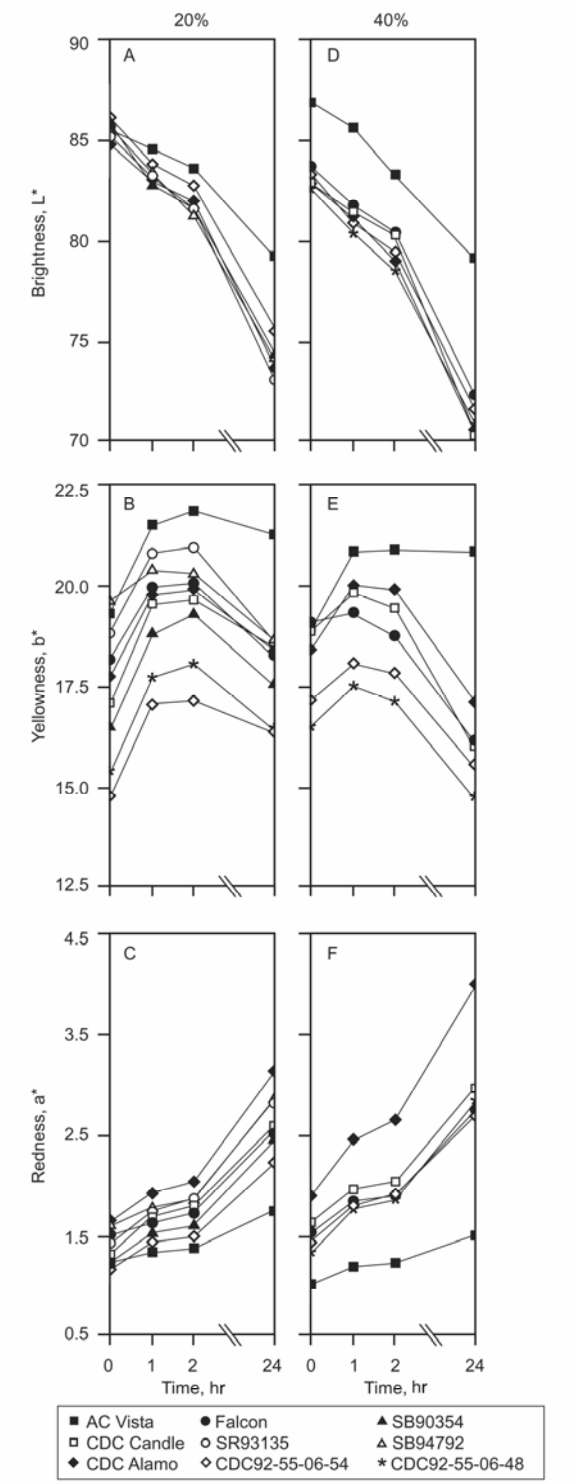

Fig. 2. Time dependent changes in color of white salted noodles with 20% (**A–C**) and 40% (**D–F**) addition of various HB flours.

Water Uptake and Solids Lost During Cooking

Water uptake was calculated by subtracting the initial sample weight (25 g) from the cooked sample weight and dividing by the initial sample weight. Cooking loss was calculated by dividing the weight of solids left in the beaker after cooking by the initial sample weight.

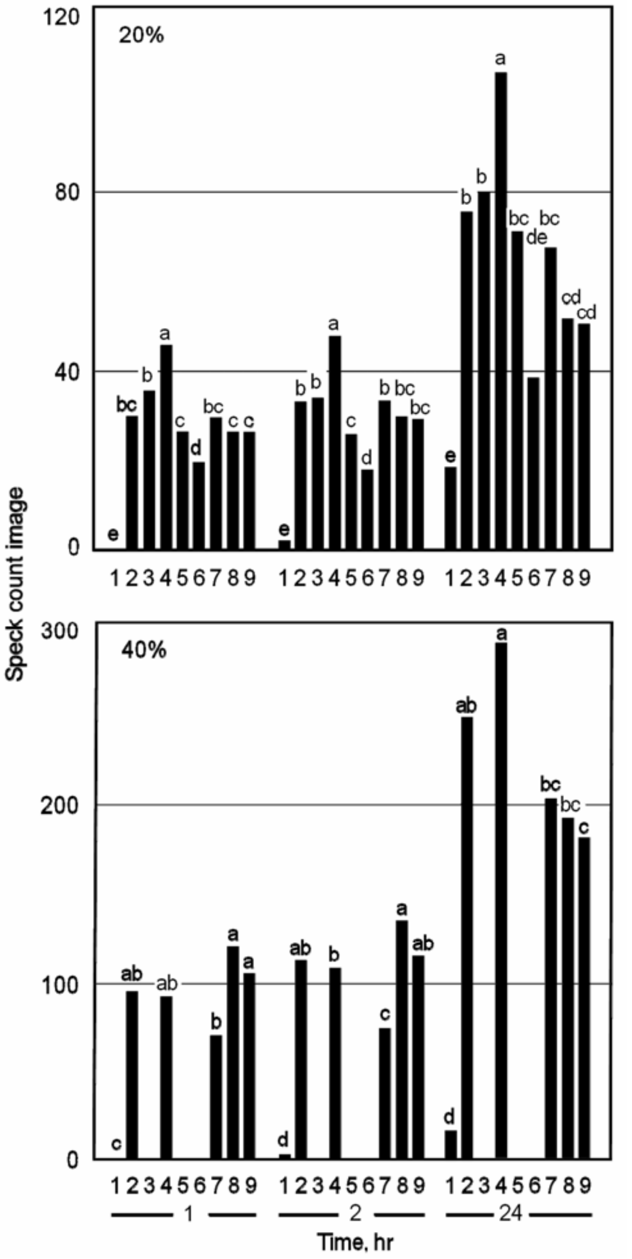

Fig. 3. Image analysis speck count of fresh white salted noodles over time with the addition of hull-less barley flour. 1, AC Vista wheat; 2, Falcon; 3, SB90354; 4, CDC Candle; 5, SR93135; 6, SB94792; 7, CDC Alamo; 8, CDC 92-55-06-54; 9, CDC 92-55-06-48. Different letters above each group indicate significant difference ($P < 0.05$).

Breaking Strength

The thickness and width were measured at two different locations on 10 dry noodle strands using digital callipers before analysis for breaking strength. Breaking strength was evaluated with a TA-XT2i texture analyser according to the method described by Oh et al (1985). A mean value of 20 noodles per sample was determined.

Statistical Analysis

All statistical analyses were performed using statistical software (v. 8, SAS Institute, Cary, NC). Analysis of variance (ANOVA) and Proc GLM were performed to determine significant differences. Replicated results are reported as means. Noodles were processed and tested using a completely randomized design. All values were considered significant at $P \leq 0.05$ unless stated otherwise. The coefficient of variation was <5% for all tests.

RESULTS AND DISCUSSION

Sheeting Energy Requirements

Incorporation of 20% HB flour significantly increased the work required to produce WSN compared with the wheat control, with the HA blended noodles requiring the highest overall work input (Fig. 1). This increase was likely due to the fact that the crumb water absorption of the blended flour was kept at the same level as that for the control. Incorporation of 40% HB flour, with the exception of HA HB, significantly reduced work input required to prepare WSN relative to the wheat control. WSN enriched with 40% normal starch HB flour required significantly lower work input than all other starch types. The observed decrease in work input at 40% enrichment may be due to the higher water absorption levels required to form proper crumbly dough characteristics (Hatcher et al 1999). Another possibility is weakening of the dough due to dilution of wheat gluten protein. Among different barley flour samples, the HA barley flour, when incorporated into the noodles, required the highest energy input. Regardless, aside from adjusting water absorption, HB-enriched noodles processed normally without evidence of either dough breakage or dough handling difficulties.

Fresh Raw Noodle Color and Appearance

Incorporation of HB flour decreased fresh WSN brightness (L^*) and yellowness (b^*) while increasing redness (a^*) relative to the wheat control (Fig. 2). These changes became more pronounced as the level of HB flour incorporation increased from 20% to 40%. The decrease in L^* and increase in a^* observed for wheat-HB flour blends would be detrimental in all markets, whereas many consumers prefer a white rather than creamy WSN color, making the b^* decrease of less importance (Hatcher 2001). The ZAW HB line CDC Alamo exhibited a distinctive increase in redness relative to the other HB genotypes, which may be related to its higher PPO activity (Table I). PPO oxidizes phenolic compounds, which react with proteins to yield red pigments (Francis and Clydesdale 1975) and polymerize in barley to produce discoloration (Jerumanis et al 1976; Theuer 2002). Barley may contain 1.2–1.5% of total polyphenols compared with only 0.02–0.04% in wheat (Theuer 2002). Alternatively, the greater discoloration of CDC Alamo may be due to elevated polyphenol content, which was not determined in this study. Quinde et al (2004) showed that total polyphenol content was significantly correlated to discoloration of barley dough sheets.

Incorporation of HB to wheat flour significantly increased the number of specks detected on fresh WSN at all time intervals (Fig. 3). WSN enriched with 40% HB flour were significantly speckier than those enriched with 20% HB flour. The specks in noodles supplemented with barley flour originate from fragments of testa, endosperm cell walls, and aleurone layer. These tissues are enriched in nonstarch polysaccharides and phenolic compounds. WSN enriched with CDC Candle were more specky at each time period than the other HB genotypes, whereas WSN enriched with SB94792 were consistently less specky than the other HB genotypes. Further studies are needed to determine whether these differences were due to genetic or eironmental factors. The increase in speckiness observed in HB flour-enriched WSN was considerably less than reported recently for HB flour-enriched fresh YAN (Hatcher et al 2005).

Average speck size of fresh WSN enriched at either level by HB flour was significantly larger than for the wheat flour fresh WSN control at 1 and 2 hr postproduction (Fig. 4). By 24 hr postproduction, average speck size of the wheat fresh WSN control was equivalent in size or larger than all HB flour-enriched fresh WSN except those enriched with the regular amylose starch cultivar Falcon.

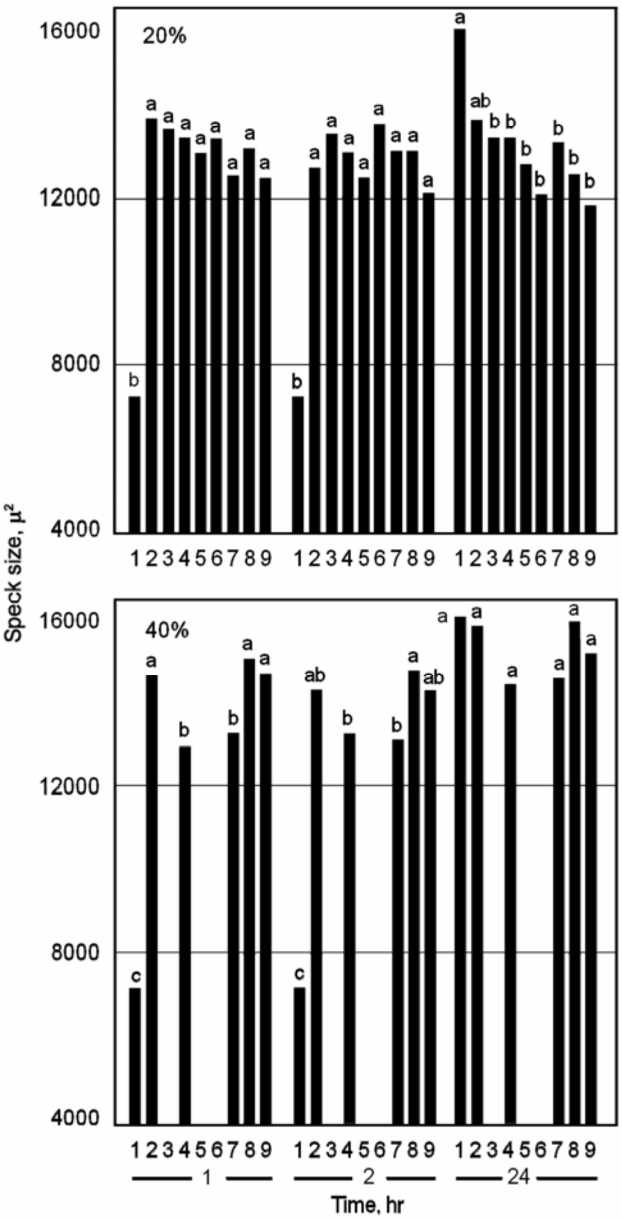

Fig. 4. Image analysis speck size of fresh white salted noodles over time with the addition of hull-less barley flour. 1, AC Vista wheat; 2, Falcon; 3, SB90354; 4, CDC Candle; 5, SR93135; 6, SB94792; 7, CDC Alamo; 8, CDC 92-55-06-54; 9, CDC 92-55-06-48. Different letters above each group indicate significant difference ($P < 0.05$).

Uncooked Dried White Salted Noodles Color

Color of uncooked dried WSN enriched with 20% HB flour was satisfactory. Slight, generally insignificant ($P > 0.05$) effects on the brightness and redness of the uncooked dried WSN were observed (Table II).

Yellowness values significantly decreased, but as noted earlier, this is preferred by some consumers. Enrichment with 40% HB imparted more pronounced trends with reduction in brightness and increase in redness being very significant.

Dried Noodle Breaking Strength

Resistance to breakage during packaging, transport, or on display is an important quality criterion for dried WSN. Noodles enriched 20% with HB flour exhibited breaking strength equivalent to the wheat control regardless of HB genotype. However, all dried WSN enriched with 40% HB flour broke at significantly lower pressures (2,200–2,350 g/mm^2) than the control (2,750 g/mm^2).

Noodle Cooking Characteristics

Fresh WSN enriched with 20% waxy or ZAW HB flour exhibited significantly reduced optimum cooking time (Table III). No change in cooking time of fresh WSN enriched with 20% normal starch or HA starch HB flour was observed. The former result is consistent with a report by Park and Baik (2004) that cooking time of fresh WSN is directly related to wheat starch amylose content. All fresh WSN enriched with 40% HB flour displayed significantly reduced cooking time, likely primarily due to the higher dough water absorption required for processing (Hatcher et al 1999).

Dried WSN noodles enriched with 20% HB flour required ≈3 min longer for optimum cooking than corresponding fresh noodles and did not differ consistently in cook time relative to the dried wheat WSN control (Table III). However, all dried WSN noodles enriched with 40% HB flour, with the exception of normal amylose starch Falcon, exhibited significantly shorter cook time than the control wheat noodles.

Water uptake during cooking for fresh WSN enriched with 20% HB flour was significantly reduced compared with the control for all HB genotypes, and decreased further when enriched 40% (Table IV). The major contributing factor to lower water uptake for fresh HB flour-enriched WSN was shorter cooking time. All dried WSN enriched with 20% HB flour exhibited comparable water uptake during cooking to the wheat control, consistent with similar cook times (Table IV). Dried WSN enriched with 40% waxy HB CDC Candle flour displayed significantly greater water uptake during cooking than the wheat control, whereas those prepared with ZAW or HA cultivars showed significant lower water uptake. All dried WSN enriched 40% exhibited a substantial reduction in water uptake during cooking that was greater than could be explained by the modest decline in cook times.

Fresh WSN enriched with 20% ZAW HB flour displayed significantly reduced cooking loss compared with the wheat control, whereas those enriched with HA flours exhibited significantly greater cooking loss (Table III). Cooking losses of fresh WSN enriched with normal HB flour were equivalent to the control. Except for one HA HB genotype, losses during cooking for fresh WSN enriched by 40% HB flour were lower than the wheat flour control. Lower solid loss during cooking for fresh WSN noodles enriched with 40% HB flour reflected reduced cook times compared with fresh WSN enriched by 20% HB flour.

There were no significant differences in cooking loss of dried WSN enriched with 20% HB flour compared with the wheat flour dried WSN control. There was no correlation between cooking time and significantly greater solid loss observed for the dried WSN containing HA HB flours compared with the other HB genotypes. Increasing HB flour enrichment level to 40% in dried WSN had little influence on solid loss during cooking.

TABLE II
Color of Uncooked Dried White Salted Noodles (WSN) Enriched with Hull-less Barley Flour[a]

	20% Enrichment			40% Enrichment		
Cultivar	***L****	***a****	***b****	***L****	***a****	***b****
Hull-less barley						
Falcon	81.03a	2.52a–c	16.87c	75.82bc	3.24a	19.44ab
SB90354	80.42a	2.65a	17.90b	nd	nd	nd
CDC Candle	81.70a	2.34c	16.77c	75.17c	3.11a	18.79b
SR93135	80.30a	2.64a	17.63b	nd	nd	nd
SB94762	80.65a	2.66a	16.96c	nd	nd	nd
CDC Alamo	80.63a	2.64a	16.16d	78.44ab	3.09a	15.81c
CDC-92-55-06-54	80.21a	2.37bc	15.45e	76.65bc	2.47b	15.81c
CDC-92-55-06-48	81.10a	2.35c	15.51e	76.90cd	2.77ab	16.42c
Wheat						
AC Vista	81.85a	2.57ab	19.62a	80.21a	2.56b	20.54a

[a] Values followed by the same letter in the same column are not significantly different ($P < 0.05$); nd, not determined.

TABLE III
Cooking Properties of Fresh White Salted Noodles (WSN) Noodles Enriched with Hull-less Barley Flour[a]

	Cook Time (min)		Water Uptake (g/g)		Cooking Loss (g/g)	
Cultivar	**20% Enrichment**	**40% Enrichment**	**20% Enrichment**	**40% Enrichment**	**20% Enrichment**	**40% Enrichment**
Hull-less barley						
Falcon	11.0a	6.5bc	1.48b	1.09cd	0.061bc	0.048c
SB90354	9.0b	nd	1.38d	nd	0.056de	nd
CDC Candle	8.5b	6.0cd	1.37d	1.17b	0.054ef	0.045d
SR93135	9.0b	nd	1.38d	nd	0.057de	nd
SB94762	9.0b	nd	1.39cd	nd	0.051f	nd
CDC Alamo	9.0b	5.5d	1.38cd	1.13bc	0.054ef	0.042e
CDC-92-55-06-54	11.0a	7.0b	1.40c	1.06de	0.071a	0.059a
CDC-92-55-06-48	11.0a	6.0cd	1.39cd	1.01e	0.066b	0.055b
Wheat						
AC Vista	11.0a	10.0a	1.53a	1.46a	0.060cd	0.058a

[a] Values followed by the same letter in the same column are not significantly different ($P < 0.05$); nd, not determined.

Cooked Noodle Texture

For consumer acceptance, HB flour-enriched WSN ideally should display similar or improved texture compared with traditional wheat flour products. Fresh WSN enriched with either 20% or 40% normal or HA HB flour exhibited comparable maximum cutting stress (MCS) to the control wheat flour noodle (Fig 5, top). MCS correlates strongly to sensory perception of noodle “bite” on front teeth (Oh et al 1983). Enrichment of fresh WSN with waxy or ZAW HB flour resulted in significant declines in MCS compared with the wheat flour control, particularly at the 40% enrichment level. All dried WSN enriched with 20% HB flour exhibited higher MCS values than corresponding fresh WSN noodles (Fig. 5, bottom). Trends in MCS attributable to HB genotype were consistent with those observed for fresh WSN. Normal and HA noodles were equivalent to the control, while waxy and ZAW noodles displayed significantly lower MCS. When dried WSN were enriched with 40% HB flour, bite comparable to the wheat control was retained only for HA enrichment. Dried WSN enriched with normal HB flour exhibited significantly lower MCS than the control, while noodles enriched with waxy or ZAW HB flour exhibited even greater declines.

Instrument measurement of resistance to compression (RTC) is strongly related to sensory perception of cooked noodle chewiness on back molars (Oh et al 1983). Fresh WSN enriched with either 20% or 40% normal or HA HB flour exhibited significantly improved noodle chewiness values over the control (Fig. 6, top). Fresh WSN enriched with 20% of either waxy or ZAW HB flours exhibited equivalent chewiness to the control, whereas chewiness was significantly lower at 40% addition.

Chewiness values for dried WSN were significantly greater than corresponding fresh WSN but followed similar trends. When prepared with either 20% or 40% normal or HA HB flour, chewiness was equivalent to that of the control, whereas when prepared with either 40% waxy or ZAW HB flour, chewiness values were significantly lower (Fig. 6, bottom).

Resilience, the ability to regain original confirmation after compression (Bourne 1976, 1978), provides insight into the structural matrix. Fresh WSN prepared with 20% normal or HA HB flours exhibited resilience equivalent to that of the wheat control noodle (Fig. 7, top). However, resilience was significantly reduced when prepared from 20% waxy or ZAW HB flours. Incorporation of 40% HB flour resulted in significant declines in fresh noodle resilience for all HB genotypes (Fig. 7, top right). For dried WSN, regardless of HB genotype, addition of HB flour at both the 20% and 40% addition levels gave resilience values equivalent to or higher than those of the control (Fig. 7, bottom).

In general, the texture of WSN made from various blends of wheat and HB flour was strongly affected by the starch characteristics of the barley flour. Enrichment with barley flour containing waxy and ZAW starch significantly decreased the firmness (MCS) and resilience of the noodles compared with a WSN wheat control. These effects may be perceived as positive in some markets like Japan where softer noodle texture is preferred (Hatcher 2001).

The impact of low-amylose starch barley flour on WSN noodle texture was consistent with recently reported results for pasta (Dexter et al 2005b) and YAN (Hatcher et al 2005). In contrast to amylose, amylopectin requires longer time and higher concentration to develop strong and rigid gels (Biliaderis 1992). The effects of low amylose HB flour on WSN texture observed in this study also are consistent with previous reports on the impact of wheat

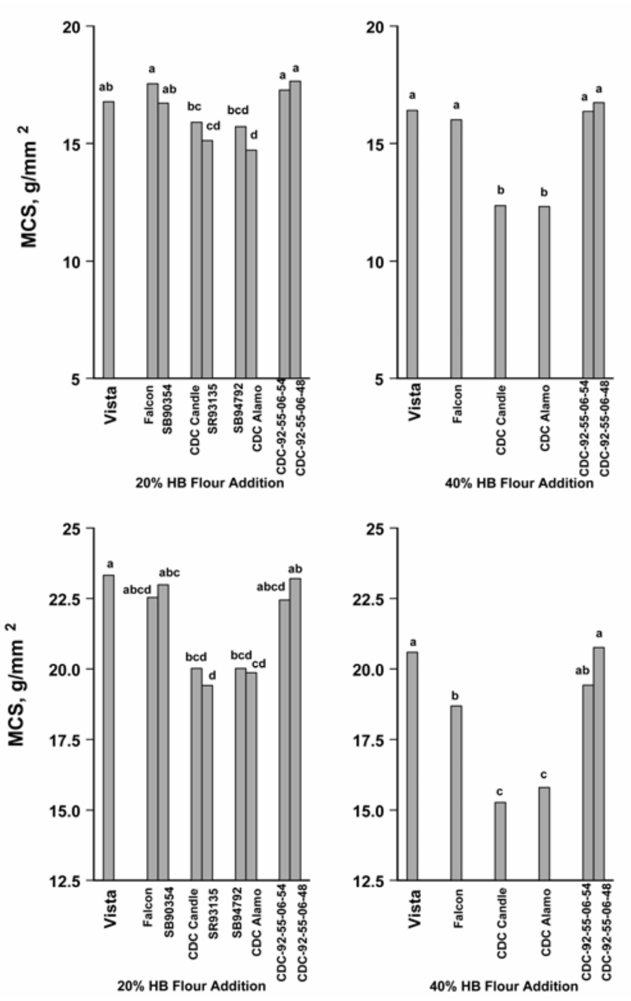

Fig. 5. Maximum cutting stress (MCS) of cooked fresh white salted noodles (top) and cooked dried white salted noodles (bottom) enriched with hull-less barley flour compared with Vista wheat flour control. Different letters above each group indicate significant difference ($P < 0.05$).

TABLE IV
Cooking Properties of Dried White Salted Noodles (WSN) Noodles Enriched with Hull-less Barley Flour[a]

Cultivar	Cook Time (min)		Water Uptake (g/g)		Cooking Loss (g/g)	
	20% Enrichment	40% Enrichment	20% Enrichment	40% Enrichment	20% Enrichment	40% Enrichment
Hull-less barley						
Falcon	14.0a	14.0a	2.06a	2.05ab	0.067b	0.066cd
SB90354	12.0b	nd	1.93b	nd	0.066b	nd
CDC Candle	13.0ab	13.0b	2.02ab	2.08a	0.064b	0.068cd
SR93135	13.0ab	nd	2.01ab	nd	0.066b	nd
SB94762	13.0ab	nd	2.03ab	nd	0.067b	nd
CDC Alamo	13.0ab	12.0c	2.04b	1.98c	0.066b	0.064d
CDC-92-55-06-54	14.0a	13.0b	1.98ab	1.85d	0.080a	0.087a
CDC-92-55-06-48	14.0a	13.0b	2.02ab	1.86d	0.078a	0.080ab
Wheat						
AC Vista	13.0ab	14.0a	2.00ab	2.04b	0.071ab	0.074bc

[a] Values followed by the same letter in the same column are not significantly different ($P < 0.05$); nd, not determined.

starch amylose content on WSN texture. Seib (2000) reported that reduced wheat starch amylose content increased wheat flour swelling ability, decreased paste gel rigidity, and enhanced deformation of gelatinized starch granules, contributing to softer texture and higher springiness of cooked noodles. Ishida et al (2003) also attributed the softer texture of WSN prepared from waxy wheat flour to starch gel properties. WSN texture can be manipulated by adjusting the proportion of flour from waxy wheat starch, higher proportions leading to lower hardness, chewiness, and gumminess characteristics (Guo et al 2003). Sasaki et al (2004) reported that WSN made from waxy wheat were soft but difficult to completely cut through. In the present study, a combination of waxy and ZAW HB starch pasting characteristics and decreased gluten content due to the replacement of 20–40% of wheat flour accounts for the altered textural properties of WSN.

WSN enriched by either 20% or 40% normal or high amylose HB flour exhibited equivalent bite and chewiness to those of the wheat flour control noodles, in agreement with our previous findings for YAN. In contrast, enriching durum wheat semolina pasta with normal or HA barley flour resulted in significant loss of firmness, which we attributed to dilution of wheat gluten protein (Dexter et al 2005b). Gluten protein is also reported to have a strong influence on noodle texture (Miskelly 1998). The anomaly may be related to pasta being dried at high temperature, which improves pasta texture due to modification of starch pasting characteristics by heat-moisture treatment (Vansteeladt and Delcour 1998). In the case of WSN, it appears that the elevated levels of β-glucan in HB flour compared with the base wheat flour may be contributing positively to texture of HB-enriched WSN. Izydorczyk et al (2002) reported that addition of β-glucan and arabinoxylan to wheat dough increased elastic and viscous moduli.

CONCLUSIONS

WSN enriched by up to 40% with HB flour were prepared with minimal processing difficulties. At 40% enrichment, β-glucan content in the WSN was >2.0% compared to <1% for the wheat base flour. Recently it was reported that for WSN and YAN prepared with a fiber-rich HB fraction, loss of β-glucan to cooking water was very low, assuring that elevated β-glucan levels in HB flour-enriched noodles remain available to consumers in the cooked product (Izydorczyk et al 2005).

Incorporation of HB flour resulted in duller, redder, and speckier fresh WSN. The color of dried HB flour-enriched WSN was somewhat better than the corresponding fresh WSN. Regardless, the HB flour-enriched WSN may be acceptable as consumers are increasingly perceiving highly refined white products as being nutrient deficient compared with darker speckier products (Stauffer 2003). The wide acceptance of darker buckwheat noodles (*soba* in Japan and *naengmyeon* in Korea) has demonstrated that consumers will accept alternative noodle products if they offer other redeeming characteristics. The lower glycemic index, reduced cholesterol,

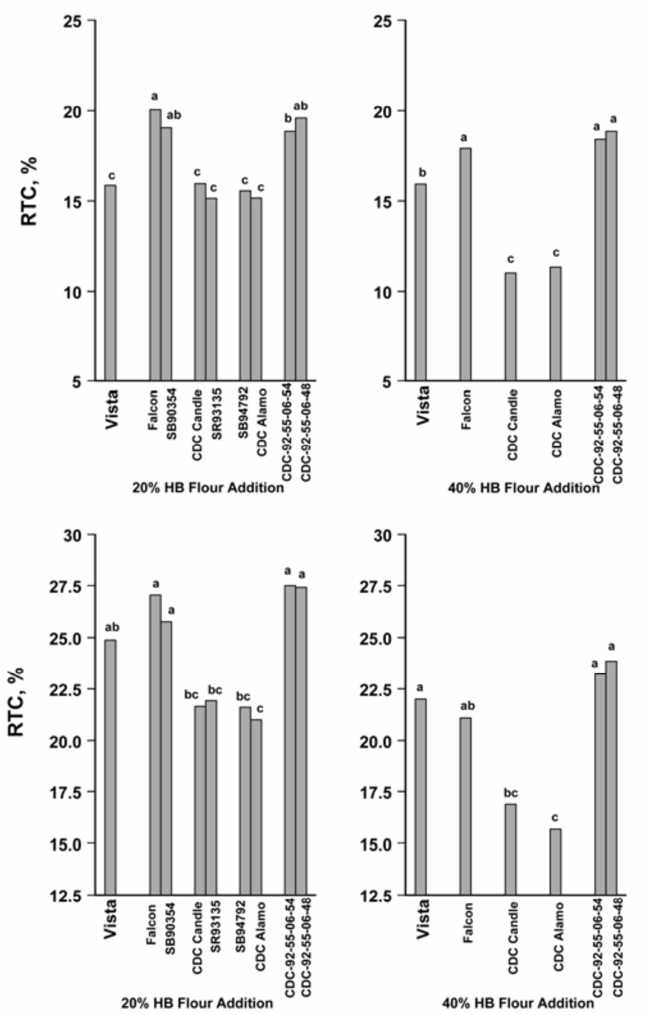

Fig. 6. Resistance to compression (RTC) of cooked fresh white salted noodles (top) and cooked dried white salted noodles (bottom) enriched with hull-less barley flour compared with Vista wheat flour control. Different letters above each group indicate significant difference ($P < 0.05$).

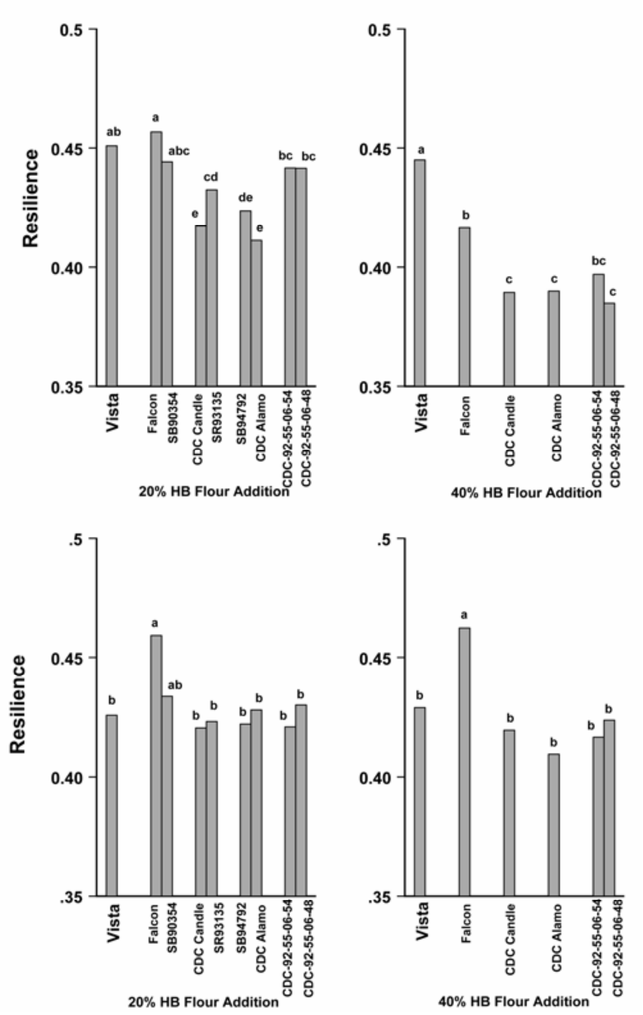

Fig. 7. Resilience of cooked fresh white salted noodles (top) and cooked dried white salted noodles (bottom) enriched with hull-less barley flour compared to Vista wheat flour control. Different letters above each group indicate significant difference ($P < 0.05$).

and decreased risk of cardiovascular disease and some forms of cancer associated with β-glucan-rich foods clearly offer significant advantages.

Incorporating HB flour of a specific starch amylose content into WSN allows the tailoring of noodle texture. Enriching wheat flour with HA or normal amylose HB flour up to 40% produced both fresh and dried WSN with excellent textural properties. Bite, chewiness, and resilience were equivalent to, or superior to, those of the control. In contrast, addition of waxy and ZAW HB flour generally resulted in dried and fresh WSN that were softer and less chewy than the wheat control, which would be considered advantageous in some markets.

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