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Full Length Research Paper

Enhancing Blue Wheat Flour and Cookie Quality via Advanced Milling Pre-treatments

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The effects of debranning levels of 4 and 8% and ultra-fine grinding on physico-chemical, rheological, and pasting properties of wheat flour obtained from blue wheat, as well as cook quality, were investigated. The process of debranning decreased ash (from1.89 to 1.62%) and wet gluten content (from 44.68 to 38.81%), but increased the gluten index of wheat flours (from 12.95 to 17.82). Debranning had positive effects on color, rheological, pasting properties and quality of blue wheat cookies. The flours by kernel ultra-fine grinding had the highest wet gluten content (44.68%), L* value (87.14), water absorption (78.8 ml/100 mg), development time (4.7 min), cookie lightness (52.49) and the lowest particle diameter, b* value (2.92), and gluten index (12.95). Samples of bran ultra-fine grinding exhibited the maximum stability time (2.1min), resistance to extension (238 EU), paste viscosities, and the highest hardness, gumminess, and chewiness values of cookie dough. Debranning and ultra-fine grinding were useful in making the good properties of wheat flour and cookies.

Key words: Blue wheat, debranning, ultra-fine grinding, cookies.

INTRODUCTION

Numerous epidemiological studies have demonstrated health benefits of consuming more wheat foods (Jacobs and Steffen, 2003; Liu, 2007). The most physiologically beneficial substances are not evenly distributed throughout the wheat kernel but concentrated in wheat bran (Betschart, 1988; Buri et al., 2004). The wheat bran contains a substantial proportion of minerals, vitamins, dietary fiber and protein in wheat grain (Pomeranz, 1988; Buri et al., 2004), and also has numerous classes of antioxidant compounds such as flavonoids, phenolic acids, carotenoids, lignans and sterol compounds (Beta et al., 2005; Yu, 2007). Bach et al. (1995) found that the digestibility of minerals, protein and non-starch polysaccharides are much higher in bran fractions rich in aleurone than in fractions rich in pericarp and testa. However, whole wheat foods are less attractive to consumers because higher levels of bran and germ reduce the quality and sensory value of the end products (Hemery et al., 2007). Furthermore, the outermost parts of wheat grain contain the majority of grain contaminants, like microorganisms, mycotoxins, pesticide residues and heavy metals (Aureli and D'Egidio, 2007; Fleurat-Lessard et al., 2007; Laca et al., 2006).

So new processes should be developed in order to exploit all the nutritional benefits of whole wheat and produce new wheat-based foods with enhanced nutritional quality and decreased contaminant content (Hemery et al., 2007). Debranning is an attractive technology, which allows a sequential and controlled removal of the outer layers of cereal kernels by abrasion and friction. After debranning, most of the pericarp of wheat grains is removed. The debranned wheat grains contain little contaminants but still contain most of the highly nutritious aleurone (Hemery et al., 2009). Ultra-fine grinding is a useful tool for making superfine powder with good surface properties like dispersibility and solubility (Tkacova and Stevulova, 1998). It has also been used to decrease the particle size of wheat bran (Hemery et al., 2011). Wang and Li (2011) recently found that the water-

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holding capacity, swelling capacity and soluble dietary fiber content of wheat bran increased after ultra-fine grinding. Thus, ultra-fine grinding seems promising to improve the nutritional potential and sensory value of whole wheat flour products.

Blue wheat contains anthocyanin compounds in aleurone while red and white wheat contains very small amount of anthocyanin (Abdel-Aal et al., 2006). The scavenging activity of free radicals for blue wheat is much higher than that of non-pigmented wheat, which is positively correlated with total phenolic content of bran and whole meal (Li et al., 2005; Hu et al., 2007). Most of the studies on blue wheat, so far, have been focusing on genetics and breeding. There are very few reports on the development of blue wheat based whole meal foods. Moreover, whole grain versions of baked goods are predicted to have substantial future growth as consumers look for more healthy alternatives (Mintel, 2009; Acosta et al., 2011). Thus, the objective of the present study was to investigate the effects of debranning and ultra-fine grinding on physico-chemical, rheological characteristics, pasting properties and cookie-making quality of whole and debranned wheat flour from blue wheat.

MATERIALS AND METHODS

The blue wheat named H4 was harvested from demonstration field of Tai'an Subcenter of National Wheat Improvement Center (Shandong province, China) during the 2010 season and provided by State Key Laboratory of Crop Biology (Tai'an, China). The demonstration field is located at 36.18°N latitude and 117.13°E longitude. Wheat sample was cleaned from foreign particles and other impurities by hand. The moisture content, test weight, thousand-kernel weight, grain size and hardness index of blue wheat grain were 11.44 g/100 g, 791.50 g/L, 30.90 g, 2.67 mm, 71, respectively. These properties were determined according to the AACC Methods (2000).

Debranning

Blue wheat was debranned with a laboratory debranning machine (6MT-5, Shandong Agriculture Machinery Institute, Jinan, China). Each trial was performed on a 1 kg batch. The blue wheat was placed in a sealed container with addition of 5% water (based on blue wheat weight) and mixed by shaking up and down several times, and then left to rest for 5 min at 25°C. In the wheat debranning procedure, the conditioning time is minimized to ensure that water only penetrates into the seed coat. This allows the protective seed coat to be stripped away layer by layer, and separately from the aleurone (Dexter and Wood, 1996). After tempering, blue wheat samples were put into the debranning machine and traveled down the abrasive chamber equipped with a rotating abrasive shaft lined with many vanes. The bran was removed by abrasion (kernels against the abrasive shaft) and, at the same time by friction (kernels against kernels). The kernels were continuously debranned for 4 or 10 min. Finally, the lid of debranning machine was removed and the debranned blue wheat was recovered. The procedure was repeated three times for each sample. "Debranning Level" index was used to evaluate the extent of debranning according to the method by Bottega et al. (2009). The debranning levels of wheat samples for debranning 4 and 10 min were approximately 4 and 8%, respectively.

Preparation of whole and debranned wheat flour

The whole and debranned blue wheat grains were used to prepare flour by three different processes.

Process I

The whole and debranned wheat grains were directly ground for 20 min by a WZJ6 vibratory micro-mill (Jinan Beili Powder Machine, Jinan, China). The flour was labeled by KUG.

Process II

After being conditioned at 15.0% moisture at 25°C for 12 h, whole and debranned wheat samples were milled with a JMFB70×30 laboratory mill (Chengdu Grain Storage Research Institute, Chengdu, China) to obtain bran and flour. The bran was micronized by a WZJ6 vibratory micro-mill (Jinan Beili Powder Machine, Jinan, China) and mixed with the flour to produce wheat flour labeled by BUG.

Process III

The whole and debranned wheat grains were milled to flour with a conventional hammer mill (Labormill 3100, Perten, Sweden). The products were labeled by HM. The particle size of different whole and debranned wheat flour was determined with a laser particle size analyzer LS 13-320 (Surplus Lab Inc., Michigan, USA). The percentages of the volume of granules with different sizes were recorded. Average and median granule diameter were calculated automatically.

Properties of whole and debranned wheat flour

The moisture and ash content of whole and debranned wheat flour were determined according to AACC Approved Methods 44-16 and 08-01 (AACC, 2000), respectively. Protein content of wheat flour was evaluated using the Kjeldahl method with a KDN-103F Analyzer (Xianjian Company Limited Shanghai, China) according to AACC Approved Method 46-11 (2000). Wet gluten content and gluten index were measured according to AACC Approved Method 38-12A (AACC, 2000). Pasting properties were determined with a Rapid Visco-Analyzer starchmaster2 (Newport, Australia) according to AACC Approved Method 76-21 (AACC, 2000). Color measurements (L*, a* and b*) were determined with a Minolta CR-400 Chromameter (Minolta Company Limited Tokyo, Japan). Rheological properties were analyzed using JFZD Farinograph and JMLD Extensometer (Dongfuhengjiu Company Limited Beijing, China) according to AACC Approved Methods 54-21 and 54-10 (AACC, 2000), respectively. The results were the mean of three measurements (n = 3).

Preparation of cookies

Cookies were made according to AACC Method 10 to 53 (2000) with minor modifications. Dough were slightly flattened with the palm of hand and laminated with a sheeter (S50, Pietro Berto, Italy) at a gap width of 5 mm. The sheets were cut with a circular cookie cutter (inside diameter: 58 mm) into dough pieces, which were immediately baked for 11 min at 205°C in an oven (T2, Zanolli, Italy). The width and thickness of cookies were measured after being cooled for 30 min.

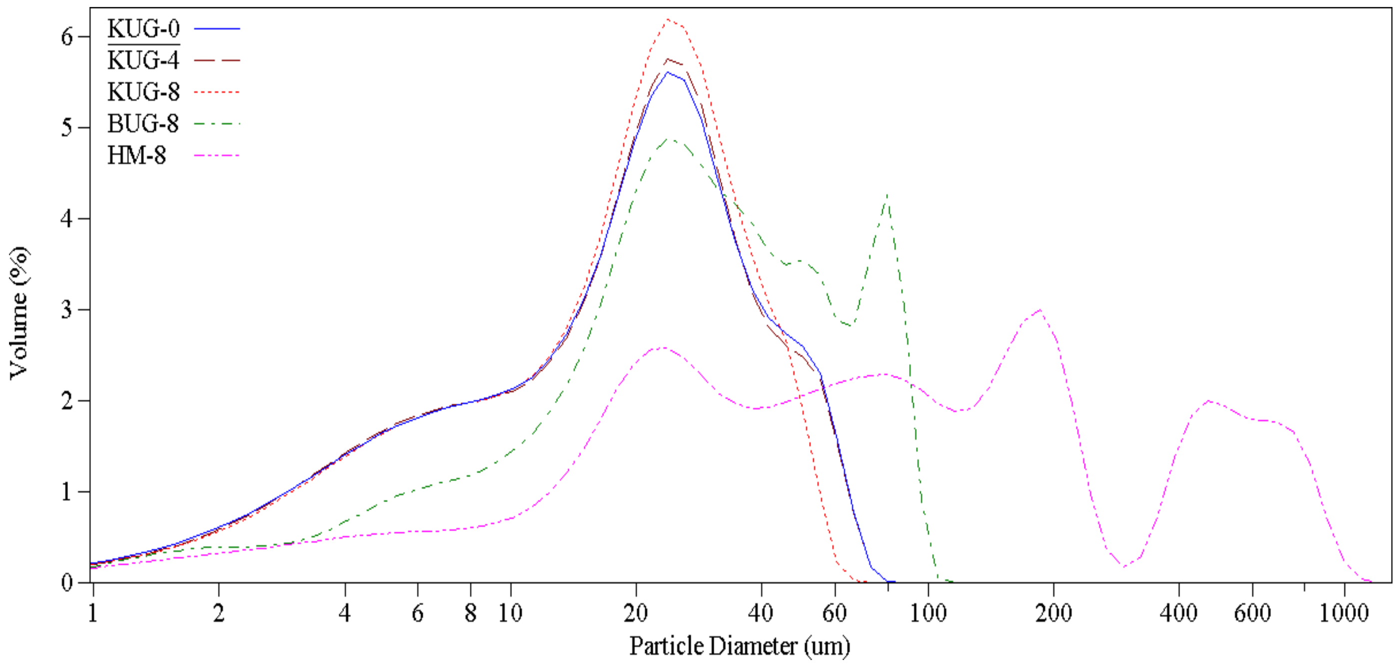

Figure 1. The particle size distribution of wheat flour in different debranning and grinding processes (KUG, kernel ultra-fine grinding; BUG, bran ultra-fine grinding; HM, hammer milling; 0, 4, 8 represent the debranning levels of 0, 4, 8%, respectively).

Textural properties of dough and cookies

Texture profile analysis (TPA) of dough was performed according to Pareyt et al. (2009) with minor modifications using a Texture Analyser TA-XT2i (Stable Micro Systems Limited Surrey, UK) equipped with a 25 kg load cell. Pre- and post-test speeds were both 2.0 mm/s, and test speed was 1.0 mm/s. Dough pieces were prepared as mentioned above and were placed on a testing plate, and compressed by 50% with a cylindrical probe (50 mm diameter). Five replications were carried out and the textural parameters of hardness, springiness, cohesiveness, resilience, gumminess and chewiness were calculated according to Bourne (1978). Cookie break strength was measured using the three point bending test (Pareyt et al., 2009). Pre-test, test and post-test speeds were 2.5, 2.0 and 10.0 mm/s, respectively. The peak force, an index of cookie break strength, was measured for at least eight cookies per sample.

Statistical analysis

The treatment mean value of each parameter was used for statistical analysis with SPSS Statistics18.0. Statistical differences were analyzed with an analysis of variance (ANOVA). Duncan's multiple range tests ($p < 0.05$) was used to detect differences among mean values of wheat flour and cookie qualities.

RESULTS AND DISCUSSION

Physico-chemical properties

According to Parker et al. (2005), Barron et al. (2007) and Hemery et al. (2009), who separated bran layers by hand dissection, the outer pericarp represents 3.5 to 4.3% of the grain, the intermediate layers (inner pericarp, testa and hyaline layer) 3.2 to 3.8% of the grain, and the aleurone layer 6.4 to 8.5% of the grain. Moreover, debranning of approximately 4% (w/w) from the wheat kernels surface suffices to remove roughly 90% of the total mould and microbial population (Mousia et al., 2004; Laca et al., 2006). Therefore, debranning up to 4% level may remove most of the outer pericarp while at 8% level the non-aleurone layer was also (partly) removed. The particle size distributions of whole and debranned blue wheat flour are shown in Figure 1. After ultra-fine grinding by the process I, the mean particle diameter of the flours did not decrease significantly, from 21.33 μm to 20.22 μm with increasing debranning level. Figure 1 shows that the ultra-fine grinding had more influence on particle size distribution of wheat flour than did hammer milling.

The curves of particle size distribution of KUG were narrower. Most of the particles of KUG had a diameter between 10 and 60 μm (Figure 1). However, the particle size distribution of HM was broader. The HM contained more coarse particles (above 100 μm) than KUG and BUG. Wheat bran is rich in fiber which is tough and difficult to grind, which caused the particle size of wheat flour to be larger and its distribution to be broader by conventional hammer milling. The particle size of milled bran in wheat flour can be decreased obviously after it was previously ultra-fine ground independently. But the flour after milling also has many large particles. The ultra- fine grinding process of whole kernel could obtain more fine particles than BUG and HM. The protein and ash

Table 1. The physico-chemical properties of wheat flour in different debranning and grinding processes.

Physico-chemical property		Debranning level (%)	Grinding process		
			KUG	BUG	HM
Protein content (%)		0	18.15±0.05a^{a}	18.19±0.09b^{a}	18.10±0.10a^{a}
		4	18.14±0.14a^{a}	18.06±0.14ab^{a}	18.08±0.15a^{a}
		8	18.05±0.10a^{a}	17.93±0.13a^{a}	18.02±0.12a^{a}
Ash content (%)		0	1.89±0.09b^{a}	1.82±0.04b^{a}	1.83±0.03b^{a}
		4	1.77±0.07ab^{a}	1.73±0.05b^{a}	1.72±0.08a^{a}
		8	1.65±0.05a^{a}	1.62±0.06a^{a}	1.64±0.04a^{a}
Wet gluten content (%)		0	44.68±0.34c^{b}	43.66±0.76b^{b}	41.15±0.07b^{a}
		4	43.78±0.07b^{c}	42.51±0.14ab^{b}	40.72±0.20ab^{a}
		8	42.76±0.21a^{b}	41.87±0.35a^{b}	38.81±1.08a^{a}
Gluten index		0	12.95±0.40a^{a}	13.58±0.08a^{a}	15.08±0.19a^{b}
		4	16.06±0.18b^{a}	16.93±0.43b^{a}	16.33±0.25b^{a}
		8	16.23±0.08b^{a}	17.19±0.35b^{b}	17.82±0.15c^{b}
Color parameters	L*	0	85.83±0.16a^{b}	81.30±0.30a^{a}	81.39±0.37a^{a}
		4	86.67±0.18b^{b}	81.81±0.16b^{a}	81.83±0.33a^{a}
		8	87.14±0.18c^{b}	81.88±0.17b^{a}	81.95±0.54a^{a}
	a*	0	-0.46±0.04c^{b}	-0.93±0.02a^{a}	0.02±0.04b^{c}
		4	-0.65±0.03b^{b}	-0.92±0.03a^{a}	-0.02±0.06b^{c}
		8	-0.74±0.03a^{b}	-0.94±0.03a^{a}	-0.10±0.04a^{c}
	b*	0	3.71±0.08c^{a}	4.89±0.11b^{b}	6.33±0.19b^{c}
		4	3.19±0.06b^{a}	4.65±0.08a^{b}	6.19±0.17b^{c}
		8	2.92±0.07a^{a}	4.62±0.03a^{b}	5.78±0.22a^{c}

KUG, kernel ultra-fine grinding; BUG, bran ultra-fine grinding; HM, hammer milling. Mean ± standard deviation values are reported (n = 3-5). Values with different superscript in a row denote significant differences among the different grinding processes ($p < 0.05$). For each parameter, values with different letter in a column denote significant differences among the different debranning levels ($p < 0.05$).

content of blue wheat flour with different treatments are shown in Table 1. As far as protein content is concerned, only BUG grinding process was slightly influenced by debranning level. At the same debranning level, differences between the grinding processes were not significant. These results are similar to those in a previous report (Singh and Singh, 2010). After ultra-fine grinding, the protein content of blue wheat flour did not vary significantly ($p < 0.05$).

In this study, after debranning, the ash content of wheat flour was slightly lower than that of untreated wheat flour. Singh et al. (1998) reported that ash content progressively decreased with the increase of debranning time for selected wheat cultivars. At the same debranning level, differences between the ash contents of wheat flours obtained by investigated grinding processes were not significant. It appears that ultra-fine grinding did not make a difference in the amount of proteins and minerals in a product, but only changed the size and structure of particles. Wet gluten content decreased gradually while the gluten index increased with increasing degree of debranning (Table 1). The decreased gluten content was probably related to the reduction of protein content by debranning. Wei (2002) reported that a higher gluten index indicated that the wet gluten was tough and not easily extendable. So these indicated that the decreased amount of bran would strengthen the network structure of gluten.

The ultra-fine grinding significantly increased ($p < 0.05$) the wet gluten content of wheat flour and kernel ultra-fine grinding offered the most obvious improvement. The plausible explanation for this variation could be ultra-fine grinding which has greatly increased the contact area of gluten protein and water. When wheat flour and water contacted, the decreased particle size also promoted water penetration. Debranning significantly influenced (p

Table 2. The rheological properties of wheat flour dough in different debranning and grinding processes.

Rheological property	Debranning level (%)	Grinding process		
		KUG	BUG	HM
Water absorption (ml/100 mg)	0	78.8±0.20b^{c}	75.7±0.70c^{b}	67.4±0.40c^{a}
	4	78.5±0.10a^{c}	74.3±0.30b^{b}	65.9±0.40b^{a}
	8	78.4±0.10a^{c}	73.2±0.20a^{b}	64.7±0.50a^{a}
Development time (min)	0	4.7±0.20b^{c}	4.0±0.20b^{b}	3.0±0.20a^{a}
	4	4.3±0.10a^{c}	3.7±0.10a^{b}	3.1±0.10a^{a}
	8	4.1±0.10a^{c}	3.7±0.06a^{b}	3.1±0.20a^{a}
Stability time (min)	0	1.8±0.20a^{ab}	2.1±0.15a^{b}	1.5±0.10a^{a}
	4	1.7±0.10a^{a}	1.9±0.25a^{a}	1.7±0.10ab^{a}
	8	1.6±0.15a^{a}	2.1±0.06a^{b}	1.7±0.06b^{a}
Softening (FU)	0	134±4.00a^{a}	164±4.00b^{b}	128±3.00b^{a}
	4	137±1.00a^{b}	161±3.00ab^{c}	126±6.00b^{a}
	8	137±2.00a^{b}	155±2.52a^{c}	117±3.00a^{a}
Energy (cm^2)	0	34±2.52a^{a}	38±1.53a^{b}	38±0.58a^{b}
	4	34±0.00a^{a}	39±1.00a^{b}	44±1.00c^{c}
	8	35±1.00a^{a}	42±0.58b^{b}	41±1.00b^{b}
Extensibility (mm)	0	137±6.00b^{b}	116±6.00a^{a}	138±0.58a^{b}
	4	140±1.00b^{b}	120±2.52a^{a}	140±2.00b^{b}
	8	124±5.51a^{a}	128±1.53b^{a}	128±0.00a^{a}
Resistance (EU)	0	170±6.51a^{a}	238±0.58a^{c}	206±1.00a^{b}
	4	172±0.58a^{a}	236±4.51a^{c}	222±7.00b^{b}
	8	202±2.52b^{a}	237±2.00a^{c}	227±4.00b^{b}

KUG, kernel ultra-fine grinding; BUG, bran ultra-fine grinding; HM, hammer milling. Mean ± standard deviation values are reported. Values with different superscript in a row denote significant differences among the different grinding processes ($p < 0.05$). For each parameter, values with different letter in a column denote significant differences among the different debranning levels ($p < 0.05$).

< 0.05) the color parameters of blue wheat flour. As was shown in Table 1, L* values increased and b*values decreased with the higher debranning levels. The removal of outer layers that were rich in pigments increased the lightness and decreased the yellowness of the grains. Moreover, the negative a* values were caused by the anthocyanin compounds in blue wheat aleurone. Grinding significantly affected the color of the blue wheat flours ($p < 0.05$). L* values were higher and b* values were lower for the KUG samples than those for the other two samples. The results showed that ultra-fine grinding of kernel wheat improved the color characteristics of whole and debranned blue wheat flour.

Rheological properties

Table 2 shows the Farinograph and Extensograph characteristics of blue wheat dough were markedly affected ($p < 0.05$) by debranning level and ultra-fine grinding. The water absorption decreased with increasing debranning level due to reduced fiber fractions. The development time of KUG and BUG samples were significantly reduced ($p < 0.05$) as a result of debranning, whereas debranning did not obviously change the stability time of the doughs. The development time decreased probably because the reduced bran shortened the water absorption process of the doughs. The values of softening of dough for debranned blue wheat flours, especially the BUG and HM samples, markedly decreased in comparison with the untreated samples. Softening of dough shows the destruction extent of dough in mixing process. It also indicates the bearing capability of dough for mechanical mixing.

This means that debranning enhanced the gluten strength to withstand mechanical shearing. In conclusion, the present results demonstrate that debranned samples exhibited stronger dough Farinograph characteristics than undebranned samples. The Farinograph characteristics of blue wheat dough in different grinding processes were studied (Table 2) and the values varied significantly ($p < 0.05$). The values of water absorption of KUG samples were higher than those of the BUG samples, followed by those of HM samples at all debranning levels. The development time had similar trends to water absorption. The value of the stability time was the highest for the undebranned BUG samples while that for the HM dough was the lowest. The possible reason was that ultra-fine grinding process resulted in smaller particle size and larger specific surface area of the wheat flour which extended the water absorption of dough.

Furthermore, more water-binding components of blue wheat flour, such as dietary fiber, protein and starch were exposed by strong mechanical power of ultra-fine grinding to significantly increase the water holding capacity of dough. Above all, the Farinograph characteristics of blue wheat dough were improved as a result of ultra-fine grinding. Extensograph analysis is significantly influenced by polymeric protein structure (Bangur et al., 1997), and, as such provides information about the viscoelastic behavior of dough. A combination of good resistance and good extensibility resulted in desirable dough properties (Rosell et al., 2001). The energy of BUG samples increased significantly ($p < 0.05$) from 38 to 42 cm^2 and that of the HM samples from 38 to 44 cm^2 with the increase of debranning level. As for the resistance to extension of blue wheat dough, the value increased observably ($p < 0.05$) from 170 to 202 EU for KUG samples and from 206 to 227 EU for HM samples. A possible explanation is that lower levels of bran in the dough altered properties of polymeric protein structure of dough, which was effective on extensibility and resistance.

The results indicate that the dough made after debranning had better extensographic properties. Energy, extensibility, and resistance of blue wheat dough for different grinding processes varied significantly ($p < 0.05$) (Table 2). KUG samples showed lower energy compared to the BUG and HM samples. Extensibility, an indicator of dough handling characteristics, of blue wheat dough for BUG declined markedly ($p < 0.05$) in comparison with the other samples. However, the dough made with BUG showed the highest resistance to extension at all debranning levels. This indicates that too many fine or coarse particles in the blue wheat flour led to more disruption of the gluten network. Therefore, the wheat flour of BUG produced stronger dough than that for KUG and HM samples.

Pasting properties

Recent researches have shown that the pasting properties of flour are related to protein content, particle size distribution, alpha-amylase content and starch damage (Mousia et al., 2004; Nagao, 1995; Wei, 2002). Table 3 clearly shows that debranning markedly changed ($p < 0.05$) the pasting properties of blue wheat flour. The peak, trough, breakdown, final and setback viscosities increased for KUG and HM with debranning at 4 and 8%. Paste viscosity is caused by the gelatinization of starch and activity of alpha-amylase in flour. The results are in line with those of a previous report (Singh and Singh, 2010), which found that paste viscosities showed strong negative relationship with the corresponding alpha- amylase activity at 4 and 8% level of debranning. α- Amylases hydrolyse glucosidic linkages, which results in the overall depolymerization of starch, consequently lowering the paste viscosity (Ragaee and Abdel-Aal, 2006). On the other hand, the reduction in protein involves higher starch content of flour.

Starch is the principal responsible of batter viscosity during heating. Consequently, the higher the protein content, the lower the viscosity (Morris et al., 1997; Oliete et al., 2010). Pasting temperature is the temperature at which the viscosity starts increasing during heating, which decreased with increasing level of debranning. Pasting temperature showed a significant negative relationship with protein content (Singh and Singh, 2010). The results revealed that debranning reduced protein content while resulted in higher pasting temperature. Among different grinding processes, the BUG samples presented the highest pasting viscosities, including peak, trough, breakdown, final and setback viscosities at all debranning levels (Table 3). This indicates that bran which has been ultra-fine grinded after milling in the blue wheat flour would have low alpha-amylase activity and increase the paste viscosities.

The breakdown viscosities of HM reduced markedly ($p < 0.05$) compared to the KUG and BUG samples. Lower breakdown indicate their greater resistance towards shear thinning. Pasting temperature was also markedly affected ($p < 0.05$) by ultra-fine grinding, and was the highest for KUG samples while the lowest for HM. For the equal weight of blue wheat flour, smaller particle size meant more particles. That is to say, the number of particles obtained by ultra-fine grinding was larger than conventional hammer milling. The results revealed that the blue wheat flour with more particles gelatinize at higher temperature.

Quality analysis of cookies

Debranning of blue wheat had significant effects on the textural properties of the dough and cookies. The values for textural parameters including hardness, springiness, cohesiveness, resilience, gumminess and chewiness decreased with the increase in debranning level (Table 4). Textural parameters are related to protein content (Singh and Singh, 2010). Thus, the results may be

Table 3. The pasting properties of wheat flour in different debranning and grinding processes.

Pasting property	Debranning level (%)	Grinding process		
		KUG	BUG	HM
Peak viscosity (cP)	0	1137±2.50a^{a}	1404±4.00a^{c}	1215±20.50a^{b}
	4	1295±13.00b^{a}	1475±13.50b^{b}	1280±11.50b^{a}
	8	1317±3.00c^{a}	1549±8.50c^{c}	1332±5.50c^{b}
Trough viscosity (cP)	0	634±1.50a^{a}	802±3.50a^{c}	712±11.00a^{b}
	4	703±1.00b^{a}	828±5.50b^{c}	742±3.50b^{b}
	8	721±1.00c^{a}	869±3.50c^{c}	773±0.00c^{b}
Breakdown viscosity (cP)	0	503±1.00a^{a}	603±7.50a^{b}	503±9.50a^{a}
	4	592±14.00b^{b}	647±8.00b^{c}	538±8.00b^{a}
	8	596±2.00b^{b}	680±5.00c^{c}	559±5.50c^{a}
Final viscosity (cP)	0	1321±4.00a^{a}	1660±5.50a^{c}	1446±12.00a^{b}
	4	1438±2.00b^{a}	1730±10.50b^{c}	1518±7.50b^{b}
	8	1463±0.50c^{a}	1799±8.50c^{c}	1587±2.50c^{b}
Setback viscosity (cP)	0	688±2.50a^{a}	858±9.00a^{c}	734±1.00a^{b}
	4	735±1.00b^{a}	901±6.00b^{c}	776±4.00b^{b}
	8	742±0.50c^{a}	930±5.00c^{c}	814±2.50c^{b}
Pasting temperature (°C)	0	87.9±0.15c^{c}	87.1±0.10c^{b}	85.6±0.05b^{a}
	4	86.7±0.05b^{c}	86.5±0.10b^{b}	85.4±0.13a^{a}
	8	86.4±0.05a^{c}	86.1±0.17a^{b}	85.2±0.03a^{a}

KUG, kernel ultra-fine grinding; BUG, bran ultra-fine grinding; HM, hammer milling. Mean ± standard deviation values are reported. Values with different superscript in a row denote significant differences among the different grinding processes ($p < 0.05$). For each parameter, values with different letter in a column denote significant differences among the different debranning levels ($p < 0.05$).

attributed to the removal of bran layers and reduced protein content by debranning. The textural properties of cookie dough in different grinding processes differed significantly ($p < 0.05$) (Table 4). BUG showed the highest textural parameters, especially hardness and gumminess, while HM samples showed the lowest values. Textural parameters are also related to gluten level and rheological characteristic of dough (Pareyt et al., 2008; Saha et al., 2011). BUG samples showed higher gluten content than HM samples and had higher gluten index than KUG samples. Moreover, the dough of BUG showed the highest resistance to extension and lowest extensibility. Consequently, the textural parameters were the highest for the cookie doughs of BUG.

The effects of debranning and ultra-fine grinding on the quality of cookies are shown in Table 5. Cookie diameter increased with increasing debranning level, while the cookie height declined at the same time. Generally, high quality of pastry flour is associated with larger sugar-snap cookie diameter (AACC 2000, 10-50D). Cookie diameter is determined by spread rate. Previous studies shown that cookie diameter and spread rate linearly decreased with increasing gluten level (Pareyt et al., 2008). This can be explained by the higher water binding capacity of gluten compared to starch. In the present study, debranning decreased the gluten content and dietary fiber (Data was not provided) in blue wheat flour which resulted in higher values of cookie diameter and spread rate. The cookie break strength ranged from 56.87 to 75.57 N, and decreased to 43.98 and 67.82 N at debranning level of 4%, to 38.20 and 62.68 N at debranning level of 8%, respectively. Dough hardness was reduced due to the removal of bran by debranning, while cookie break strength also decreased. Table 5 shows that cookie lightness was increased by debranning because of the bran layers that were rich in pigments had been striped.

It is well known that baked goods produced with 100% wheat flour are typically much darker than their refined counterparts due to the presence of finely ground bran (Friend et al., 1992). The results indicated that debranning could improve the cookie quality of blue wheat. At all debranning levels, values of cookie diameter for the BUG samples were the lowest while those for HM samples were the highest. The cookie height was

Table 4. Textural properties of cookie dough of wheat flour in different debranning and grinding processes.

Textural property	Debranning level (%)	Grinding process		
		KUG	BUG	HM
Hardness (N)	0	113.84±3.94b^{b}	139.25±8.19b^{c}	100.56±4.62c^{a}
	4	97.98±4.18a^{b}	128.18±2.88ab^{c}	84.56±4.63b^{a}
	8	92.51±7.80a^{b}	123.86±0.72a^{c}	69.45±4.59a^{a}
Springiness	0	0.45±0.03b^{a}	0.42±0.03b^{a}	0.42±0.02b^{a}
	4	0.40±0.02a^{a}	0.37±0.00ab^{a}	0.39±0.00b^{a}
	8	0.38±0.01a^{a}	0.34±0.05a^{a}	0.32±0.02a^{a}
Cohesiveness	0	0.19±0.01a^{a}	0.20±0.01b^{a}	0.19±0.02a^{a}
	4	0.18±0.01a^{a}	0.18±0.00ab^{a}	0.18±0.01a^{a}
	8	0.18±0.02a^{a}	0.17±0.00a^{a}	0.17±0.02a^{a}
Resilience	0	0.11±0.00b^{a}	0.14±0.01c^{b}	0.11±0.01b^{a}
	4	0.10±0.01a^{a}	0.13±0.00b^{b}	0.10±0.00a^{a}
	8	0.10±0.01a^{a}	0.12±0.00a^{a}	0.10±0.00a^{a}
Gumminess (N)	0	21.40±0.91b^{b}	27.55±1.16c^{c}	18.92±1.42c^{a}
	4	17.86±0.97a^{b}	23.53±1.11b^{c}	15.23±0.85b^{a}
	8	16.99±0.48a^{b}	20.91±0.46a^{c}	11.75±0.07a^{a}
Chewiness (N)	0	9.55±0.89b^{ab}	11.24±1.78b^{b}	7.82±0.71c^{a}
	4	7.06±0.42a^{b}	8.64±0.46ab^{c}	5.49±0.81b^{a}
	8	6.77±0.67a^{b}	7.07±1.14a^{b}	3.97±0.01a^{a}

KUG, kernel ultra-fine grinding; BUG, bran ultra-fine grinding; HM, hammer milling. Mean ± standard deviation values are reported. Values with different superscript in a row denote significant differences among the different grinding processes ($p < 0.05$). For each parameter, values with different letter in a column denote significant differences among the different debranning levels ($p < 0.05$).

Table 5. Parameters of cookies made of wheat flour in different debranning and grinding processes.

Cookies quality	Debranning level (%)	Grinding processes		
		KUG	BUG	HM
Cookie diameter (mm)	0	63.17±0.63a^{b}	62.08±0.14a^{a}	65.00±0.25a^{c}
	4	63.92±0.38ab^{b}	62.50±0.43ab^{a}	65.13±0.38a^{c}
	8	64.33±0.52b^{b}	63.00±0.25b^{a}	66.75±0.66b^{c}
Cookie height (mm)	0	10.17±0.14b^{a}	10.17±0.14b^{a}	10.08±0.14c^{a}
	4	9.92±0.14b^{b}	9.92±0.14ab^{b}	9.33±0.38b^{a}
	8	8.92±0.80a^{ab}	9.83±0.14a^{b}	8.83±0.14a^{a}
Breaking strength (N)	0	69.62±6.31b^{b}	75.57±2.28c^{b}	56.87±2.29c^{a}
	4	58.17±3.36a^{b}	67.82±3.46b^{c}	43.98±1.72b^{a}
	8	55.27±3.95a^{b}	62.68±1.53a^{c}	38.20±0.90a^{a}
Cookie lightness	0	51.98±1.15a^{b}	47.60±0.74a^{a}	48.14±0.61a^{a}
	4	51.86±0.32a^{b}	49.16±0.31b^{a}	48.47±1.07a^{a}
	8	52.49±0.14a^{b}	50.11±0.97b^{a}	49.71±0.83b^{a}

KUG, kernel ultra-fine grinding; BUG, bran ultra-fine grinding; HM, hammer milling. Mean ± standard deviation values are reported. Values with different superscript in a row denote significant differences among the different grinding processes ($p < 0.05$). For each parameter, values with different letter in a column denote significant differences among the different debranning levels ($p < 0.05$).

negatively related to the cookie diameter and HM cookie displayed the minimum thickness. It demonstrated that ultra-fine grinding could improve the gluten content of bran and flour which has a higher water binding capacity than HM samples. Higher cookie thickness and dough hardness determined higher cookie break strength. Cookie break strength increased from 56.87 N (HM) up to 75.57 N (BUG) for undebranned wheat. At debranning levels of 4 and 8%, the cookie break strength also had similar trends. Cookie lightness was also changed by ultra-fine grinding due to high flour lightness as was described above. KUG samples showed higher value in cookie lightness (51.98 to 52.49) compared to HM cookies (48.14 to 49.71).

Conclusion

The present study highlights the effects of debranning and ultra-fine grinding on the physico-chemical, rheological, pasting properties and cookie quality of flour from blue wheat. Blue wheat debranned to the extent of 4 and 8% revealed better properties of wheat flour and cookies, and ultra-fine grinding samples also exhibited better characteristics. Debranning yielded better color parameters, gluten index, rheological properties, pasting properties and cookie quality, and reduced particle diameter, as well as protein, ash and wet gluten content. In different grinding processes, ultra-fine grinding samples showed higher wet gluten content, L* values, rheological parameters, paste viscosities, textural values of cookie dough, cookie breaking strength, cookie lightness whereas lower particle diameter, b* values and gluten index compared to those of hammer milling samples. Debranning and ultra-fine grinding processes can significant improve the quality of wheat flour and cookies from blue wheat.

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