Effects of particle size on the properties of whole-grain soft wheat flour and its cracker baking performance

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A R T I C L E   I N F O

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Particle size distribution
Flour properties
Cracker baking performance

A B S T R A C T

In order to evaluate the effects of particle size on the properties of whole-wheat flour (WWF) and its cracker baking performance, two commercial U.S. soft wheat cultivars from different wheat classes (Eltan from Soft White Winter and Gro-Mor from Soft Red Winter) were used. Based on median diameter, WWFs of four different particle size distributions for each wheat cultivar were reconstituted after further grinding bran and shorts fractions of its corresponding flour. The median diameters of each WWF were 171.6 ± 0.3, 121.8 ± 3.4, 103.8 ± 2.1 and 89.9 ± 0.6 μm for soft white winter, and 170.0 ± 0.6, 120.8 ± 3.4, 106.3 ± 0.1 and 95.6 ± 1.8 μm for soft red winter, respectively. For both wheat cultivars, with decreasing particle size, the damaged starch contents of WWFs were increased significantly, but no significant changes in water, sodium carbonate and lactic acid-solvent retention capacity values were observed. Reduction of WWF particle size significantly affected dough rheological property, which showed an increase in the maximum resistance to extension and extensibility of cracker dough after being laminated and sheeted. Cracker baking results exhibited a significant increase in the ratio of stack height to dough weight and a decrease in bran specks on surface as WWF particle size reduced.

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1. Introduction

Due to high content of fiber and other numerous nutritional components including vitamins, minerals and phytochemicals, whole grains intake can reduce the risk of many diseases such as colon cancers, cardiovascular disease, diabetes and obesity (Liu, 2007). In recent years, consumption of products made with whole grains is being promoted globally by international organizations. However, regardless of these benefits, whole grain consumption still remains below the daily recommendations (O’Neil et al., 2010). Incorporation of whole grains in foods can reduce the risk of many diseases such as colon cancers, cardiovascular disease, diabetes and obesity (Liu, 2007). As a result, there are challenges in producing whole grain products to maintain their functionality and quality that are equivalent to the traditional products without whole grain incorporation (Chassagne-Berces et al., 2011).

In addition to the final product quality characteristics, incorporating whole-wheat flour (WWF) into a food-making system also results in many changes in dough properties and processing techniques. The particle size of WWF is an important factor affecting the qualities of whole-wheat products. Although many studies have investigated the effect of particle size on the qualities of whole-wheat products, the results remain inconclusive. Zhang and Moore (1999) reported that breads containing fine bran had lower specific loaf volume and darker crumb color than breads containing coarse or medium size bran. Cai et al. (2014) noticed lower loaf volume and greater degree of starch retrogradation during storage for breads produced from WWFs with fine brans than with coarse brans. Noort et al. (2010) reported a negative influence on bread-making quality was accelerated when bran particle size was reduced. In Asian noodle research, Chen et al. (2011) reported that the total score of dry white Chinese noodles showed a downturn with increase of particle size. Niu et al. (2014) also found the reduction of millfeeds (brans and shorts) particle sizes could provide beneficial effect on the qualities of whole-wheat raw noodles. These results suggested that the effect of...
WWF particle size on end product quality varied with the types of product and specific ranges of particle sizes. Cracker is an important part of baking industry as they are consumed by people of all age groups. Due to high water absorption and weakened gluten strength of WWF, baking qualities of whole-wheat saltine crackers are significantly impacted (Li et al., 2014). No study has been reported on the cracker baking performance of WWF with different particle sizes. The purpose of this study was to investigate the effects of WWF particle size on its solvent retention capacity (SRC) values, cracker dough resistance and extensibility, and cracker baking performance.

2. Materials and methods

2.1. Materials

Two U.S. soft wheat cultivars, Eltan from soft white winter (SWW) and Gro-Mor from soft red winter (SRW), were used in this study. Their protein contents were 9.61 ± 0.03 g/100 g and 8.62 ± 0.07 g/100 g (14 g/100 g moisture basis), respectively. After cleaning, wheat was tempered to 14.5 g/100 g moisture and milled using a pilot-scale Miag Multomalt mill (Buhler, Inc. Braunschweig, Germany) at the Wheat Marketing Center (Portland, Oregon), to obtain straight-grade flours and milled fractions (bran, shorts and red dogs). After milling, bran and shorts were each dusted one time using a laboratory bran finisher (Model MLU-302, Buhler, Inc., Braunschweig, Germany) to remove flour attaching to them. The yields of SWW milling fractions were: straight-grade flour, 72.5%; bran flour, 1.3%; shorts flour, 0.8%; bran, 18.4%; shorts, 3.3%; and red dog, 3.9%. The yields for SRW milling fractions were: straight-grade flour, 74.0%; bran flour, 1.0%; shorts flour, 0.5%; bran, 19.4%; shorts, 3.2%; and red dog, 18%.

2.2. Preparation of WWFs of different particle sizes

A flow diagram to show the processes to produce WWFs of different particle size distributions is shown in Fig. 1. To prepare for WWFs of medium particle size, bran and shorts were further ground separately for one and three times using a Perten 3100 laboratory mill (Perten Instruments, Sweden) equipped with a 0.8 mm metal mesh. To prepare for fine-grinding (fine particle size) WWFs, bran and shorts which were ground three times were separately sifted to pass through a 106 μm screen. The bran and shorts above the 106 μm screen were re-ground 4 or 5 times using the above laboratory mill equipped with a 0.6 mm metal mesh until 90% of them passed through the 106 μm screen. Then, the bran and shorts above and below the 106 μm screen were combined to maintain a constant composition. The resulting bran (No, 1st, 3rd, fine-grinding), shorts (No, 1st, 3rd, fine-grinding), bran-dusted flour, shorts-dusted flour and red dog fractions were blended with the straight-grade flours in accordance with their respective yields during milling (as shown in Section 2.1). The particle size distributions of reconstituted WWFs were determined using a Ro-Tap testing sieve shaker (WS Tyler Incorporated, USA) and median particle size was calculated according to the method described by SanzPenella et al. (2008).

2.3. Damaged starch and SRC tests

Damaged starch was determined using Chopin SDefatic according to the AACC International Approved Method 76-33.01. SRC tests, including water SRC (W-SRC), lactic acid SRC (LA-SRC), sodium carbonate SRC (SC-SRC), and sucrose SRC (Su-SRC) values of WWFs of different particle sizes, were determined according to the AACC International Approved Method 56-11.02. For the Su-SRC, a visually significant fraction of the WWF material that appeared to be an unsuitable failed to form pellet and was lost with the supernatant; as a result, we decided not to include it in our results and discussion due to unreliability issue.

2.4. Whole-wheat enzyme cracker preparation

Enzyme snack crackers were produced in this study and the formula of cracker dough was: flour (refined or WWF) 1000 g; sugar (sucrose) 80 g; shortening 120 g; dextrose 10 g; sodium chloride 10 g; sodium bicarbonate 12.5 g; ammonium bicarbonate 12.5 g; monocalcium phosphate 12.5 g; and enzyme (Crackerase, a blend of amylolytic and proteolytic enzymes derived from B. subtilis and B. amyloliquefaciens, Bio-Cat, Inc. Troy, USA) 0.15 g. Different amounts of water were added to prepare cracker dough: 27% water for the straight-grade flour dough and 33% water for WWF dough. The amount of water added to the cracker dough was based on preliminary trials according to the method described by Li et al. (2014); water was added at the minimum level of cracker flour absorption, rather than the maximum level, to develop a dough wet enough to sheet, yet dry enough to avoid the formation of an elastic dough. Before dough mixing, ammonium bicarbonate, sodium chloride and enzyme were separately dissolved in water. All ingredients were mixed in a Hobart mixer A-200 equipped with a specially designed double spiral mixing head (Poolphol Engineering Ltd., Samutprakarn, Thailand) at speed 1 for 8 min. The dough was then placed into a covered container and rested in a temperature/humidity-controlled cabinet (30 °C and 85% RH) for 2 h. Crackers were manufactured on a custom designed, pilot-scale cracker production line (Poolphol Engineer Ltd, Samutprakarn, Thailand). The settings of the process were: 1st sheeting rolls, 1.2 mm gap; lamination, 6 layers; 2nd reduction rolls, 1.4 mm gap; 3rd reduction rolls, 1-mm gap; cutting with a rolling molder.
(5.12 cm × 4.93 cm per cracker dough piece); and baking (zone 1: 210 °C; zone 2: 230 °C; zone 3: 170 °C; total baking time: 6 min). After baking, crackers were cooled to room temperature for 30 min, sealed in polypropylene bags, and stored at room temperature for quality evaluation. All quality evaluations were done in two days after baking.

2.5. Extensibility measurement of laminated cracker dough

Dough resistance to extension (maximum force) and extensibility (distance at maximum force) were measured using a TA-XTPlus Texture Analyzer (Texture Technology Corp., Scarsdale, NY, USA) equipped with a SMS/Kieffer dough and gluten extensibility rig (Model: TA-105). Before molding cracker dough pieces, a representative portion of cracker dough sheet that was laminated and sheeted was collected and placed/pressed onto the oil-coated (paraffin oil), grooved base of a Teflon dough form to generate dough strips for measuring dough rheology. After 45 min of resting of the dough on a form press in an enclosed plastic bag, 12 dough strips were taken one by one and determined for extensibility measurement. The test was performed according to the method of Singh et al. (2015), and the testing parameters were: mode, measure force in tension; option: return to start; pre-test speed: 2 mm/s; test speed: 3.3 mm/s; post-test speed: 10 mm/s; target mode: distance: distance: 30 mm; trigger force: 5 g; data acquisition rate: 500 PPS.

2.6. Cracker quality evaluation

Moisture, stack height, stack weight and texture analyses of the final products were determined. The stack height and stack weight were measured using nine cracker pieces. The stack height was measured with a vernier caliper (Mitu-toyo Manufacturing Co. Ltd., Japan), measuring once and turning crackers 90° and measuring again to obtain the average value. The breaking strength of crackers was measured by the TA-XTPlus Texture Analyzer (Texture Technologies Corp. Scarsdale, NY, USA) using the three point bending fixture (model TA-92) as described by Li et al. (2014). This adjustable three point bend/snap fixture was placed onto the TA-90 platform. An individual cracker was placed over the two legs (4.5 cm apart) and a metal knife blade (model TA-43R, 3 mm thick with rounded end) was centered over the middle of the cracker and moved downward during testing until the cracker broke. The pre-test speed, test speed, and post-test speed were 2.0 mm/s, 3.0 mm/s and 10.0 mm/s, respectively. The test distance was 35.0 mm and contact force was 5 g. The peak force displayed in the texture graph was the force required to break the cracker and was recorded as the breaking force of the cracker.

2.7. Statistical analysis

All measurements were performed at least in triplicate. Statistical analyses were carried out with the software SPSS 16.0 for Windows using one-way analyses of variance (ANOVA). P < 0.05 was considered to be statistically significant by using the Duncan’s test.

3. Results and discussion

3.1. Particle size distributions of reconstituted WWFs

The particle size distributions of WWFs are shown in Fig. 2. As expected, there was a significant decrease in the particle sizes (median diameter) of WWFs with increasing grinding times of millfeeds (brans and shorts) for both SWW and SRW samples. A large proportion of 'no-grinding' WWF retained on the top of 500 μm sieve, but after the 3rd grinding, almost all WWF passed through the 500 μm sieve. Specially, the fraction of ‘106–75 μm’ for both SWW and SRW increased proportionally from ‘no grinding’ to ‘fine grinding’ WWF samples. Nevertheless, the ‘fine-grinding’ WWFs contained much lower percentage of the fraction of ‘75–45 μm’ than the ‘no-grinding’, ‘1st grinding’, and ‘3rd grinding’ WWFs. The median diameter (89.9 ± 0.6 μm) of SWW ‘fine-grinding’ WWF was almost similar to its straight-grade flour (86.6 ± 2.5 μm); whereas the median diameter of SRW ‘fine-grinding’ WWF was 95.6 ± 1.8 μm, which was still larger than its corresponding straight-grade flour (83.6 ± 0.7 μm) (see Fig. 2).

3.2. Damaged starch and SRC profiles of WWFs

The baking industry generally prefers soft wheat flours with high gluten strength but low water holding capacity for commercial cracker production. Damaged starch generated during flour milling and arabinoxylans from the aleurone and bran layers of the wheat kernel significantly increase the water holding capacity of flour, which is an undesirable characteristic for good quality cracker flour (Slade and Levine, 1994). The damaged starch and SRC profiles of WWFs are shown in Table 1. In our study, although the bran and shorts were separately dusted to remove flour adhering to them before further fine grinding, the damaged starch in WWFs...
Table 1
Effects of particle size on solvent retention capacity (SRC) values and damaged starch content of whole-wheat flour.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Flour samples\textsuperscript{b}</th>
<th>Damaged starch (%, 14% mb)</th>
<th>SRC (%, 14% mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H\textsubscript{2}O</td>
<td>Na\textsubscript{2}CO\textsubscript{3}</td>
</tr>
<tr>
<td>Soft white winter (Eltan)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td>3.5 ± 0.2\textsuperscript{4}</td>
<td>55.9 ± 1.3\textsuperscript{b}</td>
</tr>
<tr>
<td>No</td>
<td>2.4 ± 0.2\textsuperscript{4}</td>
<td>72.1 ± 0.2\textsuperscript{a}</td>
</tr>
<tr>
<td>1st</td>
<td>3.0 ± 0.1\textsuperscript{b}</td>
<td>70.6 ± 0.4\textsuperscript{b}</td>
</tr>
<tr>
<td>3rd</td>
<td>3.1 ± 0.1\textsuperscript{b}</td>
<td>70.8 ± 0.7\textsuperscript{b}</td>
</tr>
<tr>
<td>Fine</td>
<td>3.4 ± 0.1\textsuperscript{b}</td>
<td>70.4 ± 0.2\textsuperscript{b}</td>
</tr>
<tr>
<td>Soft red winter (Gro-Mor)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td>4.0 ± 0.1\textsuperscript{a}</td>
<td>57.8 ± 0.8\textsuperscript{b}</td>
</tr>
<tr>
<td>No</td>
<td>2.6 ± 0.2\textsuperscript{4}</td>
<td>74.5 ± 0.2\textsuperscript{b}</td>
</tr>
<tr>
<td>1st</td>
<td>3.4 ± 0.3\textsuperscript{b}</td>
<td>73.6 ± 0.6\textsuperscript{b}</td>
</tr>
<tr>
<td>3rd</td>
<td>3.5 ± 0.3\textsuperscript{b}</td>
<td>73.5 ± 0.6\textsuperscript{b}</td>
</tr>
<tr>
<td>Fine</td>
<td>3.9 ± 0.2\textsuperscript{b}</td>
<td>73.2 ± 1.4\textsuperscript{b}</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Results are reported as means ± standard deviations (n = 3). Means for the same wheat cultivar in the same column followed by the same letters are not significantly different (P > 0.05).

\textsuperscript{b} Abbreviations are the same as in Fig. 2.

Increased with the increase of grinding times as some starch granules were still attached to the brans and shorts. However, the percentages of damaged starch in WWFs were not higher than their respective straight-grade flours because the damaged starch contents were calculated based on total sample weights, instead of total starch weights. WWFs contain less amounts of starch in total weights due to significant contributions by bran and germ fractions, compared with their straight-grade flours.

The water-solvent retention capacity (W-SRC) value is related to the overall water holding capacity contributed by the flour functional components, including gluten, damaged starch, and pentosans (Kweon et al., 2011b). In Table 1, the W-SRC values of WWFs were much higher than their counterpart straight-grade flours due to significant contribution by bran particles; however, they were not significantly changed by further grinding of bran and shorts. The results indicated that a similar amount of water could be used in cracker dough preparation with WWFs of different particle sizes. In addition, although median diameters of WWF flour particle sizes in ‘No grinding’ and ‘Fine grinding’ for both SWW and SRW samples had huge differences, overall contributions by each compositional component of WWFs to W-SRC were similar.

Similar to W-SRC values, the sodium carbonate (SC-SRC) values of WWFs due to particle size differences were not significantly different, but they were significantly higher than those of their counterpart straight-grade flours for both SWW and SRW (Table 1). These SC-SRC results were correlated well with the W-SRC values. The SC-SRC value does not quantify the amount of damaged starch content in flour; instead, it measures the contribution of damaged starch in flour to its baking performance. It is well known that flour with higher SC-SRC value poses a negative impact on cracker baking performance. In this aspect, it could be anticipated that WWFs would have an inferior cracker baking performance to its counterpart straight-grade flour.

Lactic acid-SRC (LA-SRC) value reflects flour gluten in functionality. LA-SRC values of WWFs were much lower than those of their counterpart straight-grade flours because of gluten dilution by bran particles of WWFs, but there was no significant change of LA-SRC values in WWFs with decreasing flour particle sizes for both cultivars (Table 1). Although bran particles in WWF may interfere with accurate LA-SRC measurement due to easy swelling of bran in lactic acid solvent, LA-SRC values were measured to compare with their counterpart straight-grade flours in this study. Between the two wheat cultivars, straight-grade flour of SWW had a higher lactic acid SRC value than that of SRW, suggesting that the SWW cultivar flour could be superior to the SRW cultivar flour in cracker baking performance.

The relationship between flour SRC profiles and cookie and cracker quality has been widely reported. In general, flour with higher LA-SRC value, and lower W-SRC, SC-SRC, and Su-SRC values is preferred for superior quality of commercial crackers for puffing and bubbling (Kweon et al., 2011b). Based on the SRC results discussed above, the impact of WWF particle size on whole-wheat cracker baking performance may not be significant.

Fig. 3. Maximum resistance to extension (a) and extensibility (b) properties of laminated whole-wheat cracker dough of different flour particle sizes. ■ soft white winter (Eltan); ▲ soft red winter (Gro-Mor). Results are reported as means ± standard deviations (n = 20). Abbreviations (SG, No, 1st, 3rd and Fine) are the same as in Fig. 2.
3.3. Extensibility measurement of laminated cracker dough

Extensibility test gives the information about the viscoelastic behavior of dough. A combination of good resistance to extension and extensibility results in desirable dough properties (Rosell et al., 2001). In general, addition of fiber into wheat flour has a negative effect on the formation of gluten network due to dilution of gluten protein (Ahmed et al., 2013) or fiber–gluten interaction (Wang et al., 2003; Noort et al., 2010). Nandeesh et al. (2011) reported that the addition of differently treated wheat bran into wheat flour resulted in stiffer dough that exhibited shorter extensibility and higher resistance to extension when evaluated with an Extensograph. However, Gül et al. (2009) showed that the addition of wheat or corn bran to dough negatively affected the maximum resistance to extension, extensibility and energy values.

Zhang and Moore (1997) found the effect of particle size on dough extensibility and resistance was not apparent after a 45 min rest period with a Farinograph. However, after a 180 min rest period, dough containing fine bran had significantly higher resistance than dough containing coarse bran. As shown in Fig. 3, all WWFs exhibited lower maximum resistance to extension and shorter extensibility than their counterpart straight-grade flours, which could be resulted from dilution of gluten protein and interference of bran to gluten development. With decreasing WWF particle sizes, however, the maximum resistance to extension and the extensibility of the laminated/sheeted cracker dough significantly increased. The results indicated that the smaller particle size of WWF resulted in stronger and more extensible dough. A common problem in the production of whole-wheat bread is the weakened gluten strength caused by the shearing and dilution of gluten by wheat bran particles (Li et al., 2012). Our results indicated that smaller bran particles had less interference with gluten formation, suggesting the whole-wheat cracker making quality could be improved by means of reducing reconstituted WWF particle sizes.

3.4. Cracker baking performance of WWFs of different particle sizes

Crackers made with WWFs of different particle sizes are shown in Fig. 4 and their quality parameters are presented in Table 2. As expected, the crackers with “No grinding” WWF showed noticeable bran spots on surface (Fig. 4). Crackers are low-moisture products and have a long shelf life. Haque et al. (2002) reported that replacement of some portion of flour with bran resulted in higher moisture contents in the final biscuit products because of extra water added in bran dough. However, Stanyon and Costello (1990) observed lower moisture content in final biscuit products with an increase of bran content in flour. In the present study, doughs formulated with WWFs were required higher amount of water for mixing due to bran and germ fractions than that with the straight-grade flour (33% vs. 27%, respectively). The same amount of water was used for all WWF doughs to maintain the same impact of total solvent (sum of sugar and water) and % sugar concentration (sugar/total solvent) of dough on cracker baking performance. Variations in total solvent and % sugar concentration could significantly affect dough property, the ratio of cracker stack height to dough weight, and geometry (width/length) of baked crackers as reported by Kweon et al. (2011a). The mixed doughs with WWFs were softer and less elastic than that with straight-grade flour due to inhibited gluten development. As a result, the final sheeted WWF doughs were thinner, resulted in lower dough weight per piece after cutting, higher moisture loss during baking (lower moisture content of baked crackers), and lower cracker stack height (Table 2 & Fig. 4).

The dough with ‘No grinding’ WWF had much lower cracker dough weight, cracker moisture content and cracker stack height than that with ‘Fine grinding’ WWF. As shown in the dough rheology data previously, the dough with larger WWF particle size (‘No grinding’) exhibited much greater noticeable differences in maximum resistance to extension as well as extensibility, compared to that with straight-grade flour. The differences between WWF dough and straight-grade flour dough properties decreased with WWF particle size reduction, which was linked well with dough weight and baking data. As a further study, it will be valuable to investigate the impact of particle size reduction of WWFs on cracker baking performance when using different amounts of water to achieve a similar dough consistency of WWFs of different particle sizes.

Different dough weights affect cracker weights, geometry and moisture contents when the same baking condition is used (Kweon et al., 2011a). In order to compare the cracker baking results of straight-grade flour with WWFs, a ratio of cracker stack height to dough weight (SH/DW) was calculated because of their dough weight variations according to Kweon et al. (2011a). Crackers made with finer particle size of WWFs yielded increased SH/DW indicating a positive impact of particle size reduction on cracker baking performance. Crackers with ‘Fine grinding’ WWF had similar SH/DW values to those with the corresponding straight-grade flour. Haque et al. (2002) found biscuits containing ground bran were thicker than biscuits containing unground wheat bran, which is generally confirmed by our results. However, Sudha et al. (2007) reported that incorporation of wheat bran decreased the spread of biscuits without much change in the thickness of the biscuits.

Cracker texture is another important quality parameter and subsequent acceptance by consumers. Breaking force reflects the hardness of crackers and a higher breaking force value indicates a harder texture. Cracker texture is significantly affected by its moisture content. Crackers with lower moisture contents would be much easier to break than those with higher moisture contents. Addition of coarse millfeeds fractions (bran and shorts) into straight-grade flour yielded a significant decrease in the breaking force of crackers (such as ‘No grinding’ and ‘1st grinding’ in Table 2). Too low breaking force also means the crackers are too fragile and could cause too much breakage in packaging. As the WWF particle
sizes reduced, the breaking force of the crackers increased which coincided with their increased moisture contents. Sudha et al. (2007) and Nandeesh et al. (2011) reported soft biscuits (cookies) become harder with the incorporation of various types of brans because the biscuit spreads were reduced. However, Li et al. (2014) found saltine crackers with higher level of WWF were more fragile (less breaking force). In our study, breaking force was positively correlated with cracker stack height (SWW, r = 0.961, p < 0.01) and moisture content (SWW, r = 0.982, p < 0.01; SRW, r = 0.971, p < 0.01) based on Pearson’s correlation analysis. Cracker with high moisture content and stack weight tends to have more leathery texture, which increases breaking force.

At the same particle size levels, SWW flour showed larger cracker height and breaking force values than SRW flour because of its high gluten strength as determined by lactic acid-SRC values of their corresponding straight-grade flours. Kweon et al. (2011a) suggested that gluten performance index [LA-SRC/(SC-SRC + Suc-SRC)] for a flour was a better predictor of resulting baked cracker geometry than the LA-SRC alone. Gluten performance index of each WWF and SRW straight-grade flour was 0.663 and 0.598, respectively, which confirmed that WWF cultivar produced better crackers than SRW cultivar for both straight-grade flour and WWFs. Although Suc-SRC of WWF cannot be used for predicting baking performance due to unreliability in measurement, LA-SRC and gluten performance index data of straight-grade flour can be used as a valuable tool to predict its WWF baking performance in whole-wheat crackers.

Overall results suggest that reducing particle size of WWFs to 90–96 μm (median diameter) could significantly improve cracker baking performance, which enables to produce whole-wheat crackers similar to refined wheat flour crackers with respect to geometry and texture. However, further reduction of bran particle sizes to 47.9 μm (median diameter) could impose a negative effect on the gluten network formation of dough as measured by the gluten yield and result in poor bread quality (Noort et al., 2010). Li et al. (2012) reported that the whole-wheat bread (WWB) made from WWF of average particle size of 96.99 μm had better baking quality than those of the breads made from WWF of two other particle sizes, 50.21 and 235.40 μm. T_{2} relaxation time as measured by the Magnetic Resonance Imaging (MRI) technique indicated that the decreased particle size of WWF increased the water absorption of Arabinoxylans (AX) gels, which led to water migration from the gluten network to the AX gels and yielded inferior baking quality of WWB (Li et al., 2012). Our results showed that finer bran WWF resulted in more extensibility and resistance of cracker dough than coarser bran WWF, which indicated that smaller bran particles (90–96 μm median diameter) had less interference with gluten formation. These results further supported the findings of Li et al. (2012) on the effect of the WWF particle sizes on the water migration between AX gels and gluten matrix in a whole-wheat dough system. In addition, wheat bran is not a standardized product with defined quality and chemical composition. The composition of commercial bran depends upon many factors, which include wheat class, grain shape and size, thickness of the bran layers, milling system and type of flour produced (Zhang and Moore, 1997).

4. Conclusions

Particle size reduction of WWF increased damaged starch content measured but did not significantly affect SRC values (water, sodium carbonate and lactic acid). Dough rheological property of laminated/sheeted cracker dough exhibited higher maximum resistance to extension and longer extensibility as WWF particle size decreased, which indicated finer bran particle sizes (90–96 μm median diameter) had less interference with gluten formation and was more desirable for whole-wheat crackers. Overall dough rheology and cracker baking results showed that controlling WWF particle size could be an effective approach to improve the quality of whole-wheat crackers. To alter WWF particle sizes, the impact of grinding methods should be considered but they were not investigated in the study.

References


Table 2

<table>
<thead>
<tr>
<th>Flour samples(a)</th>
<th>Moisture (g/100 g)</th>
<th>DW(c) (g)</th>
<th>SH(d) (cm)</th>
<th>SH/DW(d)</th>
<th>SW(g)</th>
<th>Breaking force (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft white winter (Eltan)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td>4.32 ± 0.18(c)</td>
<td>66.5 ± 2.4(d)</td>
<td>5.34 ± 0.14(e)</td>
<td>0.080 ± 0.05(f)</td>
<td>49.35 ± 1.25(e)</td>
<td>3454.1 ± 235.8(g)</td>
</tr>
<tr>
<td>No</td>
<td>1.96 ± 0.28(c)</td>
<td>53.8 ± 0.8(d)</td>
<td>3.43 ± 0.08(f)</td>
<td>0.064 ± 0.02(g)</td>
<td>38.44 ± 1.00(h)</td>
<td>1515.2 ± 143.8(i)</td>
</tr>
<tr>
<td>1st</td>
<td>2.68 ± 0.09(c)</td>
<td>56.7 ± 1.4(d)</td>
<td>3.92 ± 0.09(f)</td>
<td>0.069 ± 0.06(g)</td>
<td>40.40 ± 0.67(e)</td>
<td>1954.1 ± 196.6(i)</td>
</tr>
<tr>
<td>3rd</td>
<td>2.79 ± 0.18(c)</td>
<td>59.5 ± 1.9(d)</td>
<td>4.29 ± 0.07(f)</td>
<td>0.072 ± 0.04(g)</td>
<td>41.55 ± 0.42(e)</td>
<td>2149.2 ± 194.2(i)</td>
</tr>
<tr>
<td>Fine</td>
<td>3.41 ± 0.49(c)</td>
<td>60.6 ± 1.0(d)</td>
<td>4.76 ± 0.07(f)</td>
<td>0.078 ± 0.02(g)</td>
<td>42.62 ± 0.63(e)</td>
<td>2384.9 ± 173.0(i)</td>
</tr>
<tr>
<td>Soft red winter (Gro-Mor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SG</td>
<td>3.90 ± 0.26(c)</td>
<td>63.5 ± 0.2(d)</td>
<td>4.84 ± 0.06(f)</td>
<td>0.076 ± 0.04(g)</td>
<td>46.52 ± 0.49(e)</td>
<td>2595.5 ± 198.6(i)</td>
</tr>
<tr>
<td>No</td>
<td>1.81 ± 0.08(c)</td>
<td>53.9 ± 1.9(d)</td>
<td>3.24 ± 0.05(f)</td>
<td>0.060 ± 0.02(g)</td>
<td>38.19 ± 0.29(e)</td>
<td>1131.6 ± 129.5(i)</td>
</tr>
<tr>
<td>1st</td>
<td>2.10 ± 0.08(c)</td>
<td>55.6 ± 1.4(d)</td>
<td>3.94 ± 0.05(f)</td>
<td>0.071 ± 0.04(g)</td>
<td>39.30 ± 0.23(e)</td>
<td>1582.7 ± 108.1(i)</td>
</tr>
<tr>
<td>3rd</td>
<td>2.49 ± 0.16(c)</td>
<td>56.5 ± 2.1(d)</td>
<td>4.32 ± 0.07(f)</td>
<td>0.076 ± 0.03(g)</td>
<td>40.56 ± 0.46(e)</td>
<td>1735.8 ± 88.8(i)</td>
</tr>
<tr>
<td>Fine</td>
<td>3.03 ± 0.22(c)</td>
<td>58.8 ± 2.7(d)</td>
<td>4.36 ± 0.09(f)</td>
<td>0.074 ± 0.03(g)</td>
<td>41.95 ± 0.34(e)</td>
<td>2233.1 ± 176.0(i)</td>
</tr>
</tbody>
</table>

\(a\) Results are reported as means ± standard deviations (n = 20). Means for the same wheat cultivar in the same column followed by the same letters are not significantly different (P > 0.05).

\(b\) Abbreviations are the same as in Fig. 2.

\(c\) DW, dough weight of nine cracker dough pieces; SH, Stack height of nine crackers; SW, Stack weight of nine crackers (dry basis).

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