The characteristics of steamed bread from reconstituted whole wheat flour (WWF) of different U.S. hard wheat classes with different bran particle size distributions

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Executive Summary

In this study we compared three US wheat classes, hard white (HW), hard red winter (HRW) and hard red spring (HRS), along with different particle size distributions of bran (53µm, 74µm, 105µm and 125µm), and assessed their potential in steamed bread. Refined flour was prepared from all 3 classes and reconstituted with its respective bran fraction at different particle size distributions to make a model WWF.

- Results showed that the damaged starch content of refined HW flour and reconstituted HW WWF was 3.23%~3.70%; refined HRW flour and reconstituted HRW WWF was 5.45%~5.92%; and refined HRS flour and reconstituted HRS WWF was 4.04%~4.35%. These are low values for hard wheat flours, both refined and whole wheat.
- Farinograph and SRC results showed that the water absorptions of all reconstituted WWF were increased compared to control flours, as expected.
- Farinograph and Mixolab tests both showed the peak time and stability of the HRW WWF increased compared to refined HRW. The opposite trend was observed for HW WWF and HRS WWF, and may be related to differences in wheat class gluten characteristics.
- For reconstituted WWF steamed bread quality, the specific volumes of all three groups decreased with the addition of bran, and WWF flour with smaller bran particle sizes exhibited the lowest specific volumes (HWb74: 2.16 cc/g; HRWb53: 2.22 cc/g; HRSb53: 2.13 cc/g).
- The L value and whiteness index both decreased with smaller bran particle size distributions, meaning the color was less white and bright.
- From texture profile analysis, adding bran increased both the firmness and chewiness.

Based on this study, a bran particle size distribution of 105µm - 125µm is recommended for HW, HRW and HRS to achieve larger specific volume coupled with softer, less chewy texture.

Key words: hard white wheat, hard red spring wheat, hard red winter wheat, bran, bran particle size distribution, reconstituted whole wheat flour, steamed bread

Introduction

Steamed bread is one of the most popular breakfast foods in Taiwan. Taiwan's Department of Statistics points out that the annual output value of baked and steamed food is about 6.2 billion NT dollars (Yang, 2020). In China, steamed bread is divided into two styles, northern and southern, and most steamed bread in Taiwan is of the northern style. Northern style steamed bread is larger and has less sugar and fat than the southern style. Because of its simple formula, changing the type of flour may change the quality of northern style steamed bread.

Whole grain foods are good for health, and whole wheat flour is commonly used in baked and steamed wheat-based products to meet whole grain requirements. Whole wheat flour refers to a flour that uses 100% of the wheat kernel, including all bran, germ and endosperm materials. Although most consumers know that using whole wheat flour to make baked or steamed products is beneficial for health, changes in taste and texture brought about by whole wheat flour affect consumer purchasing decisions. Finding a balance between health benefits and desirable flavor/texture is one of the current aims of designing a healthy diet.

Using whole wheat flour to replace refined flour is not always straightforward. The presence of the bran and germ results in changes in product color, texture, and flavor, to name a few. Bran particle size plays a role in some of these changes, and some can be negative while others can be positive. Some studies showed that smaller bran particle sizes had a beneficial effect on Asian noodles and some baked products (Chen et al., 2011; Wang et al., 2016). Other studies indicated that the presence of bran in dough not only affects gluten structure (Bock and Damodaran, 2013), but also affects gas cells in the dough (Gan et al., 1989; Chen, 2018), which affects the appearance and quality of the bread. Therefore, the bran is also considered to be an important factor affecting the structure and properties of bread (Bock et al., 2013; Chen, 2018; Bock, 2019).

In this study, three different classes of wheat (HW, HRW and HRS) and four different particle size distributions of bran (53µm, 74µm, 105µm and 125µm) were blended at a ratio of 85% refined flour + 15% bran to create reconstituted whole wheat flour (WWF) and make reconstituted WWF northern steamed bread. The purpose of this study was to investigate the effects of reconstituted WWF particle size on flour characteristics and northern steamed bread quality.

Materials and methods

Materials

Wheat from three U.S. wheat classes [hard white (HW), hard red winter (HRW) and hard red spring (HRS)] were used in this study. Their protein contents (14% mb) were 12.7% (HW), 11.6% (HRW) and 14.4% (HRS). The three wheat samples were tempered in plastic buckets at room temperature to a final moisture of 14.5% and milled on a Miag Multomat experimental mill (Bühler Inc., Plymouth, MN). The refined flours (HWf, HRWf and HRSf) were the controls in this study. Bran from each respective wheat sample was milled by Prater Industries (Bolingbrook, IL) on a laboratory scale air classifier mill to four particle size distribution targets with D(50) values of 53 µm, 74 µm, 105 µm and 125 µm. Other materials included instant dry yeast (Lesaffre Yeast Corp., Milwaukee, WI), sugar, salt and shortening (Crisco, J.M. Smucker Co., Orrville, OH).

Preparation of reconstituted whole wheat flours (WWF)

After milling, control flours (HWf, HRWf and HRSf) were mixed with bran from each particle size distribution target at a ratio of 85% refined control flour to 15% bran (w/w) to create reconstituted whole wheat flour (WWF). The final sample set included: HW (HWb53, HWb74, HWb105 and HWb125), HRW (HRWb53, HRWb74, HRWb105 and HRWb125), and HRS (HRSb53, HRSb74, HRSb105 and HRSb125).

Flour composition and quality analyses

All samples were analyzed for moisture, protein, ash and damaged starch contents according to AACC Approved Methods (44-15A; 08-01; 46-30; 76-33.01, respectively). Because the SD-matic (Chopin Technologies, France), an amperometric method, has not been evaluated for measurement of starch damage in WWF, an enzyme-based starch damage assay kit (Megazyme, Chicago, IL) was also used to quantify starch damage using AACC Method 76-31.01.

To evaluate the flour quality characteristics (polymer swelling, water absorption, stability, starch gelatinization, retrogradation and extensibility), Solvent Retention Capacity (SRC) (AACC Method 56-11.02), Farinograph (AACC Method 54-21.01) (C.W. Brabender, South Hackensack, NJ), Mixolab (AACC Method 54-60.01) (Chopin Technologies, France) and Kieffer rig extensibility (Texture Technologies, Hamilton, MA) tests were conducted. The Kieffer rig extensibility test was partially modified according to the method described by Londono et al., (2014). Dough samples were prepared as appropriate for full formula steamed bread production. After dough sheeting, the dough was flattened with a rolling pin and placed on a grooved base with a Teflon coating. A flat top piece was applied to the dough on the grooved base and pushed down firmly by tightening a clamp until the two pieces come together to separate the dough into strips. The mold and clamp apparatus was then placed in a closed plastic bag to relax for 45 minutes (30°C, 85% RH). After the relaxation period, the clamp and flat top piece were removed and the dough strips removed one for extensibility measurement on the TA.XTPlus (Texture Technologies, Hamilton, MA). The test parameters were pretest speed, 2.0 mm/s; test speed, 3.3 mm/s; post-test speed, 10 mm/ s; trigger force, 5 g; and data acquisition rate, 200 PPS.

Steamed bread preparation

Fig. 1 outlines the steamed bread making process. The formula included:

400 g flour
8 g instant dry yeast
180 – 200 g water
32 g sugar
1.2 g salt
16 g shortening

The yeast, sugar and salt were each dissolved separately in water. The mixtures were then added to the flour and mixed in a Hobart mixer (Model A-120, Hobart Manufacturing Co., Troy, OH) equipped with a special double spiral head at speed 1 for 1 minute. The shortening was then added and mixed into the dough at speed 1 for another 1.5 minutes. The final dough was rested in plastic bag for 10 minutes before sheeting until the surface was smooth (10-12 passes) using an Oshikiri sheeter/molder (Model WFS, Oshikiri Machinery Ltd., Japan). The dough sheet was rolled into a cylinder by hand to 36 cm and cut into 6 equal parts (5 cm/ piece). One piece of dough (25 g) was placed in a 45 mL plastic centrifuge tube before proofing. Initial dough volume was 21-22 mL. The dough pieces were then proofed (30°C, 85% RH) in a proofing cabinet (Model LRPR-2, LBC Bakery Equipment, Everett, WA) until the volume of dough in the centrifuge tube reached 40-45 mL. The remaining 5 pieces of dough were steamed for 15 min using a convection oven (Model SCCWE 62G, Rational AG, Germany).

Fig. 1. Steamed bread making steps

Quality evaluation of steamed bread

All steamed bread samples were evaluated for specific volume, exterior color and texture. The specific volume of steamed bread was determined using a laser volume analyzer (BVM-L370, TexVol Instruments Inc., Sweden) and dividing the measured volume by the weight of the bread piece. The exterior L, a, b color was determined using a chroma meter (CR-410, Konica Minolta Sensing Inc., Japan). The texture profile analysis (TPA) of the steamed bread was determined using the TA.XTPlus Texture Analyzer equipped with a 35 mm acrylic cylindrical probe. Steamed bread was sliced horizontally, and a flat piece of 15 mm thickness was compressed to 50% of its original height. The test conditions were: pretest speed, 2 mm/s; test speed, 1 mm/s; post-test speed, 1 mm/s; and trigger force, 5 g.

Statistical analysis

All measurements were performed at least in triplicate. The results of the study were presented as the average ± standard deviation. Significant differences were analyzed by the Duncan's multiple-range test ($P < 0.05$) using SAS statistical analysis software for analysis of variance (ANOVA).

Results

Compositional analysis

Table 1 shows the moisture, protein, ash and damaged starch contents of the bran, refined flours and reconstituted WWF used in this study. The moisture content of the control flours (HWf, HRWf and HRSf) was 13.00 – 13.75% and consistently greater than that of the reconstituted WWF (12.25 – 12.74%). This is reasonable as the bran had a moisture content of 6.69% and would naturally reduce the average moisture content of the reconstituted WWF. Ash content was greater for the reconstituted WWF, as expected, due to the presence of bran. However, there were few significant differences in protein content on the addition of bran.

Damaged starch content of the control flours varied depending on wheat class, likely due to differences in kernel texture and milling characteristics. Starch damage, in order from greatest to least, was as follows: HRWf (5.92%) > HRSf (4.35%) > HWf (3.23%). Surprisingly, adding 15% bran only had a small effect on the damaged starch content within the same class of wheat. Regrinding of bran normally increases starch damage in the residual endosperm removed with the bran fraction. It is possible that the air classification strategy used to regrind the bran for this study may have improved bran passage through the screen, thereby minimizing excessive grinding and subsequent starch damage.

Table 1. Composition and damaged starch content of refined flour and reconstituted WWF

Sample	Moisture	Protein	Ash	Damaged Starch (SD-matic)
	%	0% moisture basis		%
Bran(125μm)	6.69±0.20	15.79±0.02	6.00±0.01	- -
HWf	13.75±0.01^{a}	13.77±0.04^{c}	0.55±0.01^{c}	3.23±0.12^{e}
HWb53	12.49±0.01^{ef}	13.65±0.03^{bc}	1.46±0.05^{a}	3.70±0.12^{d}
HWb74	12.56±0.02^{e}	13.85±0.05^{bc}	1.40±0.01^{ab}	3.59±0.04^{d}
HWb105	12.71±0.04^{d}	13.95±0.04^{b}	1.43±0.02^{ab}	3.39±0.11^{de}
HWb125	12.74±0.04^{d}	13.81±0.09^{bc}	1.43±0.01^{ab}	3.49±0.17^{de}
HRWf	13.00±0.04^{c}	12.36±0.32^{e}	0.61±0.01^{c}	5.92±0.07^{a}
HRWb53	12.25±0.11^{h}	12.77±0.01^{d}	1.36±0.04^{b}	5.45±0.17^{b}
HRWb74	12.37±0.04^{g}	12.63±0.15^{d}	1.36±0.05^{b}	5.74±0.14^{b}
HRWb105	12.50±0.05^{ef}	12.80±0.04^{d}	1.36±0.03^{b}	5.92±0.26^{ab}
HRWb125	12.42±0.02^{fg}	12.66±0.10^{d}	1.41±0.03^{ab}	5.65±0.25^{b}

HRSf	13.17±0.08^{b}	15.66±0.02^{a}	0.59±0.09^{c}	4.35±0.12^{c}
HRSb53	12.44±0.01^{fg}	15.67±0.06^{a}	1.36±0.00^{b}	4.23±0.11^{c}
HRSb74	12.52±0.04^{ef}	15.81±0.22^{a}	1.40±0.02^{ab}	4.23±0.13^{c}
HRSb105	12.59±0.01^{e}	15.74±0.16^{a}	1.41±0.03^{ab}	4.27±0.05^{c}
HRSb125	12.57±0.02^{e}	15.77±0.04^{a}	1.39±0.00^{ab}	4.04±0.10^{c}

n=3

Values followed by the different letters in the same column are significantly different ($P < 0.05$).

Damaged starch content

Damaged starch is one of the most important factors affecting quality characteristics of flour (Keskin et al., 2012). There two approved methods for determining damaged starch as distinguished by their measurement principle: amperometric (SD-matic) and enzymatic hydrolysis (Megazyme) methods.

The amperometric method (AACC 76-33) uses the absorption kinetics of iodine, as measured by an amperometric probe, to express the damaged starch content. The other method is based on enzymatic hydrolysis under given temperature, pH and enzyme conditions. In that method, α-amylase acts on the flour sample to break down the starch into reducing sugars, and starch damage is calculated according to the amount of reducing sugars produced.

A comparison of the starch damage results obtained from each method are presented in Table 2. Looking at the refined flours, all samples exhibited greater starch damage using the SD-matic compared to the Megazyme method. It is apparent that the results are influenced by the measurement method, and this holds for refined as well as WWF. What is interesting, though, is that general ranking of samples did not change between the two methods. That is, the order of starch damage from greatest to least within a wheat class was generally similar for both methods.

Whereas the Megazyme method is considered a direct method for damaged starch measurement, the amperometric method utilized by the SD-matic is indirect. Thus, a slight algorithm correction to the SD-matic may be necessary to pull these results into better alignment. Given the advantages of the SD-matic (shorter test time, fewer reagents, less technical skill required), it is an acceptable means of differentiating damaged starch content of WWF in industrially relevant settings.

There are two points to pull from this methodological comparison:

1) The damaged starch values measured by each method do not agree in terms of absolute value. However, the ranking of samples within a wheat class remain generally consistent, showing that the results are correlated.
2) The addition of bran, regardless of particle size, results in a generally consistent level of starch damage that is not necessarily greater than that of the refined flour when an air classified grinding process is used to reduce bran particle size.

Table 2. Damaged starch content of refined flour and reconstituted WWF as measured by the SD-matic and Megazyme methods

	SD-matic	Megazyme
	%	
HWf	3.23 ± 0.12^{e}	4.04 ± 1.06^{f}
HWb53	3.70 ± 0.12^{d}	5.17 ± 0.10^{de}
HWb74	3.59 ± 0.04^{d}	5.08 ± 0.04^{e}
HWb105	3.39 ± 0.11^{de}	4.99 ± 0.28^{e}
HWb125	3.49 ± 0.17^{de}	4.98 ± 0.16^{e}
HRWf	5.92 ± 0.07^{a}	7.20 ± 0.47^{a}
HRWb53	5.45 ± 0.17^{b}	6.55 ± 0.20^{b}
HRWb74	5.74 ± 0.14^{b}	6.62 ± 0.08^{b}
HRWb105	5.92 ± 0.26^{ab}	6.73 ± 0.15^{b}
HRWb125	5.65 ± 0.25^{b}	6.58 ± 0.15^{b}
HRSf	4.35 ± 0.12^{c}	5.71 ± 0.09^{c}
HRSb53	4.23 ± 0.11^{c}	5.62 ± 0.09^{cd}
HRSb74	4.23 ± 0.13^{c}	5.61 ± 0.10^{cd}
HRSb105	4.27 ± 0.05^{c}	5.65 ± 0.04^{c}
HRSb125	4.04 ± 0.10^{c}	5.57 ± 0.22^{cd}

n=3 to 5

Values followed by the different letters in the same column are significantly different ($P < 0.05$).

SRC profiles

SRC tests, including water SRC (W-SRC), lactic acid SRC (LA-SRC), sodium carbonate SRC (SC-SRC), and sucrose SRC (Su-SRC), are shown in Table 3.

Water SRC (W-SRC) is influenced by the swelling of gluten, damaged starch, and pentosans (Kweon et al., 2011b), and it provides an overall picture of flour water requirements. The W-SRC values increased with the addition of bran, but the values were greater with smaller particle sizes. It is likely that the larger surface area to volume ratio of smaller bran particles allowed for increased water uptake.

Lactic acid SRC (LA-SRC) is specific for swelling of gluten polymers, specifically glutenins, with greater values indicating stronger gluten and/or greater protein content. The protein contents of HWf, HRWf and HRSf were 13.77%, 12.36% and 15.66%, respectively, and the LA-SRC values were on the order of HRSf > HRWf > HWf, indicating that although HWf has a higher protein content than HRWf, the gluten strength is lower than HRWf. After adding bran, the LA-SRC values of all classes decreased compared with their control groups. This indicates bran dilution of gluten properties, and this may be exacerbated by bran interference with gluten polymer swelling. Bran particle size did not greatly impact overall LA-SRC or gluten performance index (GPI) values. It therefore appears that the effect of bran on LA-SRC is more dependent on its presence rather than its particle size.

Sucrose SRC (Su-SRC) shows the characteristics of pentosans and, to a lesser extent, gliadins. Su-SRC tracks with pentosans such that the lower the Su-SRC value, the lower the pentosan content of the flour. The bran contains more pentosans than the endosperm, and hence the reconstituted WWF have greater values than the control flours. Different bran particle sizes did affect the value of Su-SRC, with smaller bran particles showing increased Su-SRC values. The pentosans in smaller bran particles, by virtue of the greater surface area to volume ratio, would be more accessible to the solvent than those in larger bran particles. However, the exception was the HRW WWF, where nearly all samples had similar Su-SRC values to the control.

Sodium carbonate SRC (SC-SRC) is related to the level of damaged starch, as only damaged starch is accessible to the solvent relative to an intact starch granule. The SC-SRC values of the control groups (HWf, HRWf and HRSf) show that the content of damaged starch from low to high was HWf< HRSf< HRWf. This aligns with the starch damage values reported in Tables 1 and 2. The reconstituted WWF SC-SRC values for HW, HRW and HRS were greater than the control groups, in contradiction to the damaged starch values reported in Tables 1 and 2. This indicates that both the SD-matic and Megazyme methods may not be as accurate in measuring starch damage in samples where bran is present, or that another component is also swelling in the presence of SC.

Table 3. SRC profiles of refined flour and reconstituted WWF

	Water	Lactic acid	Sucrose	Sodium carbonate	GPI*
			%, as-is		
HWf	58.6±0.7^{f}	155.3±8.9^{c}	102.2±2.4^{g}	71.7±0.7^{f}	0.89±0.05^{c}
HWb53	70.1±0.9^{b-d}	116.0±2.0^{h}	111.6±1.7^{e}	80.6±1.0^{de}	0.60±0.01^{i}
HWb74	69.5±2.8^{b-d}	116.0±2.1^{h}	112.2±2.1^{e}	79.4±0.6^{e}	0.61±0.01^{hi}
HWb105	68.6±0.4^{d}	118.2±1.0^{h}	111.4±1.6^{e}	80.2±1.3^{e}	0.62±0.01^{hi}
HWb125	68.7±1.4^{d}	118.2±2.3^{h}	107.5±1.5^{f}	79.8±0.9^{e}	0.63±0.01^{hg}
HRWf	62.0±0.7^{e}	199.9±1.7^{b}	116.2±1.5^{d}	84.6±0.6^{c}	1.00±0.01^{b}
HRWb53	72.7±1.8^{a}	138.3±1.5^{e-g}	120.2±1.9^{ab}	88.7±1.0^{b}	0.66±0.01^{ef}
HRWb74	71.4±1.3^{a-c}	134.6±2.3^{fg}	116.6±0.8^{d}	90.5±1.0^{a}	0.65±0.01^{fg}
HRWb105	71.3±1.3^{a-c}	136.3±1.9^{e-g}	117.9±1.6^{b-d}	88.7±0.5^{b}	0.66±0.01^{ef}
HRWb125	69.4±0.8^{cd}	133.8±3.4^{g}	117.0±2.0^{d}	87.9±0.9^{b}	0.65±0.01^{fg}
HRSf	61.1±0.9^{e}	208.5±3.2^{a}	110.5±1.6^{e}	81.9±1.3^{d}	1.09±0.01^{a}
HRSb53	71.5±1.6^{ab}	142.4±3.5^{d}	121.5±2.1^{a}	87.4±1.7^{b}	0.68±0.02^{de}
HRSb74	70.4±1.0^{ab}	139.7±3.6^{d-f}	119.9±1.5^{a-c}	87.5±0.4^{b}	0.68±0.02^{d-f}
HRSb105	70.4±0.8^{b-d}	140.5±1.6^{de}	117.5±1.3^{cd}	88.7±1.2^{b}	0.68±0.01^{de}
HRSb125	69.3±0.9^{cd}	141.5±2.6^{de}	116.7±1.5^{d}	87.8±0.7^{b}	0.69±0.02^{d}

n=3

Values followed by the different letters in the same column are significantly different ($P < 0.05$).

* Gluten performance index (GPI)= Lactic acid SRC/(Sodium carbonate SRC + Sucrose SRC)

Farinograph characteristics

Table 4 shows the Farinograph results for the refined flours and reconstituted WWF. The water absorption (WA) of HW and HRS increased when 15% bran was added compared with controls, but the both development time (DT) and stability (ST) for the WWF were shorter. The HRW group proved the be the exception to this trend. The WA of HRWf was 58.1% with a DT of only 2.2 minutes and a ST of 8.1 min. After adding 15% bran, the water absorption increased, but DT and ST also tended to increase with the size of the bran particles. It may be that HRW bran provided structural reinforcement, thereby increasing dough resistance against the mixing blades and delaying curve departure from 500 BU as observed by other researchers (Marti et al., 2015; Peressini and Sensidoni, 2009).

Table 4. Farinograph mixing properties for refined flour and reconstituted WWF

	WA	DT	ST
	%, as-is	min	min
HWf	56.2±0.0^{k}	5.9±0.1^{b}	9.7±1.0^{c-e}
HWb53	64.3±0.1^{d}	4.5±0.3^{de}	5.7±0.1^{e}
HWb74	63.5±0.0^{g}	4.4±0.1^{de}	8.4±1.2^{b-e}
HWb105	63.2±0.0^{h}	4.7±0.0^{de}	8.3±1.9^{b-e}
HWb125	63.2±0.0^{h}	4.2±0.5^{e}	6.0±1.3^{de}
HRWf	58.1±0.2^{g}	2.2±0.2^{f}	8.1±0.5^{c-e}
HRWb53	64.6±0.1^{c}	4.3±0.6^{e}	9.5±1.3^{a-c}
HRWb74	64.2±0.0^{de}	5.2±0.0^{b-d}	11.5±2.0^{ab}
HRWb105	63.8±0.0^{f}	6.0±0.3^{b}	12.2±0.4^{a}
HRWb125	64.0±0.0^{ef}	4.7±0.2^{de}	11.0±0.6^{a-c}
HRSf	61.0±0.0^{i}	7.4±0.2^{a}	11.0±1.5^{a-c}
HRSb53	67.4±0.0^{a}	5.6±0.6^{bc}	8.9±1.9^{a-e}
HRSb74	67.5±0.0^{a}	5.0±0.8^{c-e}	9.2±0.6^{b-e}
HRSb105	67.1±0.4^{b}	5.3±0.1^{b-d}	8.1±2.8^{b-e}
HRSb125	67.0±0.0^{b}	5.2±0.4^{b-d}	9.1±1.1^{a-e}

n=3

Values followed by the different letters in the same column are significantly different ($P < 0.05$).

Mixolab characteristics

Mixolab results for the refined and reconstituted WWF are shown in Table 5. C1 represents the time required for flour to reach peak development while stability indicates how long the dough is stable during mixing at 30°C. These parameters are somewhat analogous to DT and S in the Farinograph, although there are significant differences between the tests (i.e. mixing geometry, mixing speed, total dough mass, etc.) (Collar and Rosell, 2013). Similar to the results from the Farinograph, the addition of bran to HRW resulted in an increase in C1 as well as the stability. HRS also followed Farinograph trends, with the addition of bran resulting in slight decreases in C1 and stability. HW broke from this pattern and exhibited slight increases in C1 and stability with bran addition. In all cases, bran particle size distribution did not appear to affect the overall results. What this indicates is that bran may have a reinforcing effect on HRW doughs, whereas it is likely more destabilizing in HRS and HW doughs, likely as a result of different protein quantity and quality among the classes.

C2 is a low viscosity point in the curve that occurs when heating is initiated. It typically occurs around ~50°C before starch begins to gelatinize, and it provides information on gluten strength through thermally-induced restructuring of low energy interactions (i.e. hydrogen bonds and/or hydrophobic interactions) (Dubat, 2013). The three refined flours grouped closely in terms of C2 values, revealing that there are few differences among the classes in terms of gluten softening on heating. However, the introduction of bran affected each class differently. HRS showed little change on the addition of bran, which is in line with the gluten from HRS being among the strongest among all U.S. wheat classes. HW showed small changes as well, and although the changes appeared to be minimal as in the case of HRS, the slightly larger average changes of C2 for HW on the whole indicate a weaker gluten than that of HRS. HRW exhibited the greatest change in C2 values on the addition of bran, suggesting that HRW has the weakest gluten of the three classes. It is worth reiterating that the differences in C2 values among the classes is small, and that all of them exhibit gluten quality that is appropriate and acceptable for hard wheat.

Points C3, C4 and C5 are related to starch pasting properties. C3 is the peak of the viscosity curve during heating and is related to starch gelatinization and pasting properties. Again, all three wheat classes clustered between 1.63 – 1.93 Nm. HRW starch appeared to be the least affected by the presence of bran. Indeed, the C3 value was almost constant across the whole HRW sample set. HRS and HW showed small increases in C3 values when bran was present, although the differences were not practically significant.

C4 is the lowest viscosity point after the C3 peak, and it generally coincides with the cooling phase of the test. In many cases, it is regarded as an indication of amylolytic activity. However, as the grain samples all exhibited Falling Number values in excess of the 300 sec threshold and no exogenous amylase was added after milling, the C4 value in this study is related to shear thinning of the dough after starch gelatinization. HRS and HRW both showed more substantial drops in C4 values relative to their respective C3 values compared to HW. Although bran particle size did not affect C4 values, the wheat class differences show HW to be slightly more resistant to shear thinning than HRW and HRS.

Retrogradation potential is indicated by the C5 value, also called setback in starch pasting terminology. This is the final viscosity at the end of the test after a full heating and cooling cycle. HW exhibited the greatest setback value, meaning that its amylose more quickly reassociates after gelatinization. This has implications for texture and shelf-life of products, with greater setbacks generally leading to firmer textures and greater rates of staling (i.e. shorter shelf-life). It might be expected, then, that HW products will potentially stale faster than HRS or HRW products.

Table 5. Mixolab characteristics of refined flours and reconstituted WWF

	C1	Stability	C2	C3	C4	C5
	Min		Nm			
HWf	3.88	8.00	0.46	1.79	1.72	3.47
HWb53	4.32	8.70	0.48	1.88	1.72	3.13
HWb74	4.90	8.60	0.52	1.91	1.78	3.34
HWb105	4.28	8.70	0.49	1.93	1.78	3.40
HWb125	4.98	8.70	0.48	1.93	1.77	3.30
HRWf	1.93	9.20	0.49	1.89	1.44	2.74
HRWb53	4.30	10.60	0.54	1.90	1.44	2.74
HRWb74	5.87	10.40	0.53	1.89	1.39	2.72
HRWb105	5.32	10.20	0.53	1.89	1.39	2.75
HRWb125	5.42	10.10	0.52	1.89	1.38	2.65
HRSf	5.75	8.80	0.43	1.63	1.24	2.40
HRSb53	5.05	8.00	0.46	1.71	1.31	2.53
HRSb74	5.22	7.90	0.44	1.69	1.30	2.49
HRSb105	5.20	8.00	0.45	1.70	1.29	2.51
HRSb125	5.00	8.70	0.46	1.71	1.31	2.53

n=3

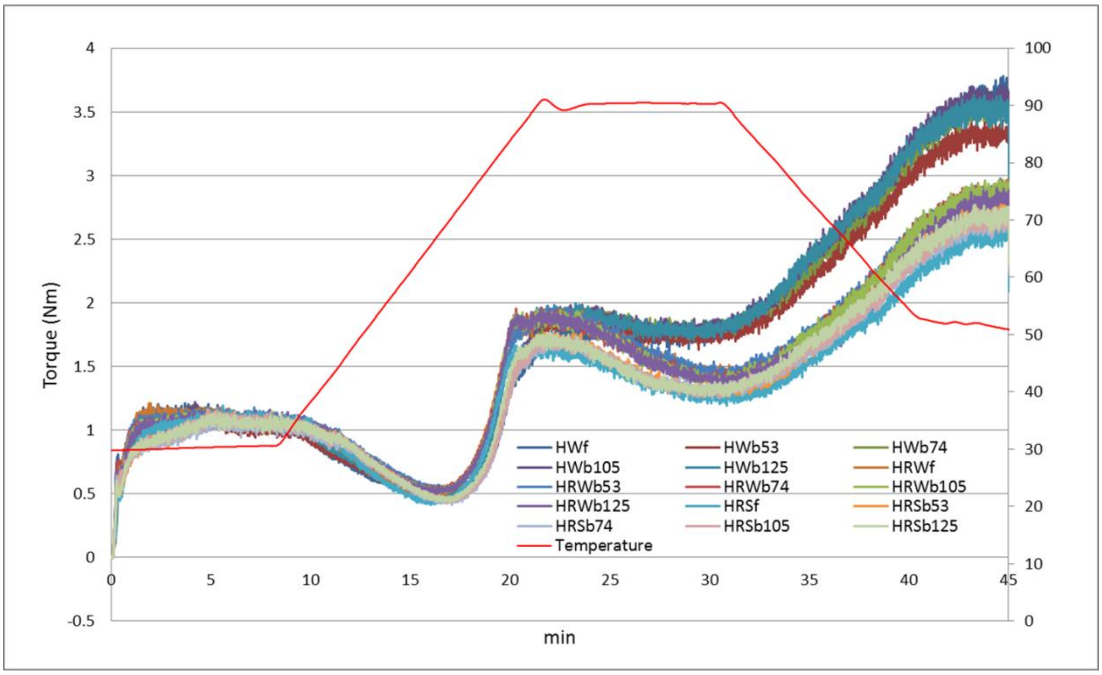

Fig. 2. Mixolab curves of refined flours and reconstituted WWF

Extensibility of steamed bread doughs

Table 6 displays the extensibility results of full formula steamed bread dough from refined flours and reconstituted WWF. HRSf showed the greatest extensibility value among the control flours. Although HWf and HRWf displayed less extensibility than HRSf, they were more statistically similar to one other and in the same general range as HRSf. The addition of bran reduced extensibility across all wheat classes. Bran is known to physically interrupt the gluten network, introducing localized weak spots; this results in premature rupturing of the dough during extensibility testing. In the cases of HRW and HW, the bran particle size did not appear to play a large role in the extent of extensibility loss. However, HRS showed a trend of greater extensibility loss as bran particle size increased, likely as a result of larger bran particle introducing larger localized disruptions of the gluten network. The general lack of response to bran particle size in the HW and HRW samples may be a function of protein content and/or gluten relaxation kinetics in the presence of bran.

The resistance to extension is generally used as a proxy for gluten strength in flour + water doughs, although it is not as straightforward in full formula doughs. HWf stood out among the control flours for displaying the least resistance to extension. This is interesting given its apparent strength in Farinograph and Mixolab tests. HRSf was expected to exhibit the greatest resistance to extension through a combination of having the greatest protein content and strength. However, in this dough formula, it falls between HWf and HRWf. Being the weakest of the control flour samples in

Farinograph and Mixolab testing, it was surprising to see HRWf provide the greatest resistance to extension. The departure of the three wheat classes from expected trends is likely a result of ingredient interactions in the full formula dough. Interestingly, HRW samples still stand out from HRS and HW samples in terms of bran particle size trends. Increasing bran particle size resulted in a decrease in HRW resistance to extension. HW and HRS exhibited the opposite trend, in this case exhibiting greater resistance to extension with increasing bran particle size. In general, it may be that smaller bran particles create multiple small points of weakness in the gluten network, and these may add up to a greater decrease in overall resistance. It is unclear why the classes exhibited different trends with bran particle size, although HRW samples also deviated from HRS and HW samples in Farinograph and Mixolab characteristics. Thus, it seems likely to be related to gluten protein characteristics based on overall class genetics.

The resistance to extension (R/E) value shows the balance of elastic to viscous properties of the dough after relaxation. The larger the R/E value, the stronger the gluten and/or less the extensibility (Preston and Hoseney, 1991). The HRW samples showed the greatest R/E values compared to the HRS and HW samples. This shows that HRS and HW maintain slightly more extensibility relative to a similar amount of strength compared to HRW. Although we have not identified an optimal R/E value for whole wheat steamed bread, it seems likely that HRS and HW might produce steamed bread of greater specific volume based on their respective extensibilities while the resistance exhibited by HRW may limit expansion.

Table 6. Extensibility of steamed bread dough made from refined flour and reconstituted WWF

	Resistance to Extension	Extensibility	R/E
	g	mm	
HWf	19.61±2.11^{g}	41.83±10.03^{b}	0.51±0.24^{g}
HWb53	20.76±1.81^{g}	19.76±2.64^{gh}	1.06±0.13^{de}
HWb74	20.54±1.46^{g}	19.88±3.64^{gh}	1.07±0.22^{de}
HWb105	23.85±2.64^{f}	21.83±10.41^{gf}	1.18±0.26^{d}
HWb125	25.70±1.56^{de}	19.45±3.12^{gh}	1.35±0.18^{c}
HRWf	30.66±4.00^{b}	38.17±6.95^{c}	0.85±0.30^{g}
HRWb53	33.22±1.69^{a}	17.59±1.40^{h}	1.90±0.19^{a}
HRWb74	26.17±3.76^{de}	17.40±2.25^{h}	1.54±0.37^{b}
HRWb105	25.83±2.21^{de}	17.65±3.43^{h}	1.53±0.43^{b}

HRWb125	25.85±2.16[de]	17.95±3.64[gh]	1.48±0.23[bc]
HRSf	28.37±3.76[c]	47.22±5.81[a]	0.61±0.14[g]
HRSb53	25.27±1.38[d-f]	29.74±4.15[d]	0.86±0.11[f]
HRSb74	25.14±2.18[ef]	28.07±4.71[de]	0.92±0.18[ef]
HRSb105	27.06±0.93[cd]	26.32±2.74[de]	1.04±0.11[de]
HRSb125	34.74±3.19[a]	24.53±2.07[ef]	1.43±0.18[bc]

n=3

Values followed by the different letters in the same column are significantly different (P < 0.05).

Steamed bread specific volume

Table 7 displays the specific volume data for steamed breads made from refined flours and reconstituted WWF. The order of specific volumes for steamed breads from the control flours was HWf > HRSf > HRWf (2.92, 2.61 and 2.48 cc/g, respectively), although these differences are not statistically significant within this data set. The addition of bran universally resulted in decreased specific volume across all classes. A clear trend was also observed for bran particle size, with smaller bran particle sizes exhibiting a smaller specific volume. When compared with the specific volume of their respective control flours, HWb125 decreased by 16.4%, HRWb125 decreased by 6.0%, and HRSb125 decreased by 11.9%, respectively. Therefore, combined with the results in Tables 4 – 6, it can be understood that bran with a smaller particle size may be more likely to affect the formation of the network structure during dough mixing and thereby decrease extensibility and gas retention of the dough to the extent that the specific volume of the end product is affected. Steamed bread made with a bran particle size distribution mean of 125μm is able to achieve larger specific volumes across all wheat classes.

Fig 3-5 show the exterior and interior of the northern steamed breads from each refined flour and reconstituted WWF.

Table 7. Specific volume of steamed breads made from refined flours and reconstituted WWF

	Specific Volume cc/g	Relative change in specific volume %
HWf	2.92 ± 0.04[a]	–
HWb53	2.28 ± 0.07[c]	-21.9
HWb74	2.16 ± 0.09[d]	-26.0

HWb105	2.38 ± 0.06^{b}	-18.5
HWb125	2.44 ± 0.02^{b}	-16.4
HRWf	2.48 ± 0.04^{a}	–
HRWb53	2.22 ± 0.05^{c}	-10.5
HRWb74	2.31 ± 0.06^{b}	-6.9
HRWb105	2.27 ± 0.04^{b}	-8.5
HRWb125	2.33 ± 0.08^{b}	-6.0
HRSf	2.61 ± 0.04^{a}	–
HRSb53	2.13 ± 0.06^{d}	-18.4
HRSb74	2.14 ± 0.07^{d}	-18.0
HRSb105	2.21 ± 0.05^{c}	-15.3
HRSb125	2.30 ± 0.08^{b}	-11.9

n=3

Values followed by the same letter in the same column and wheat class are not significantly different ($P < 0.05$)

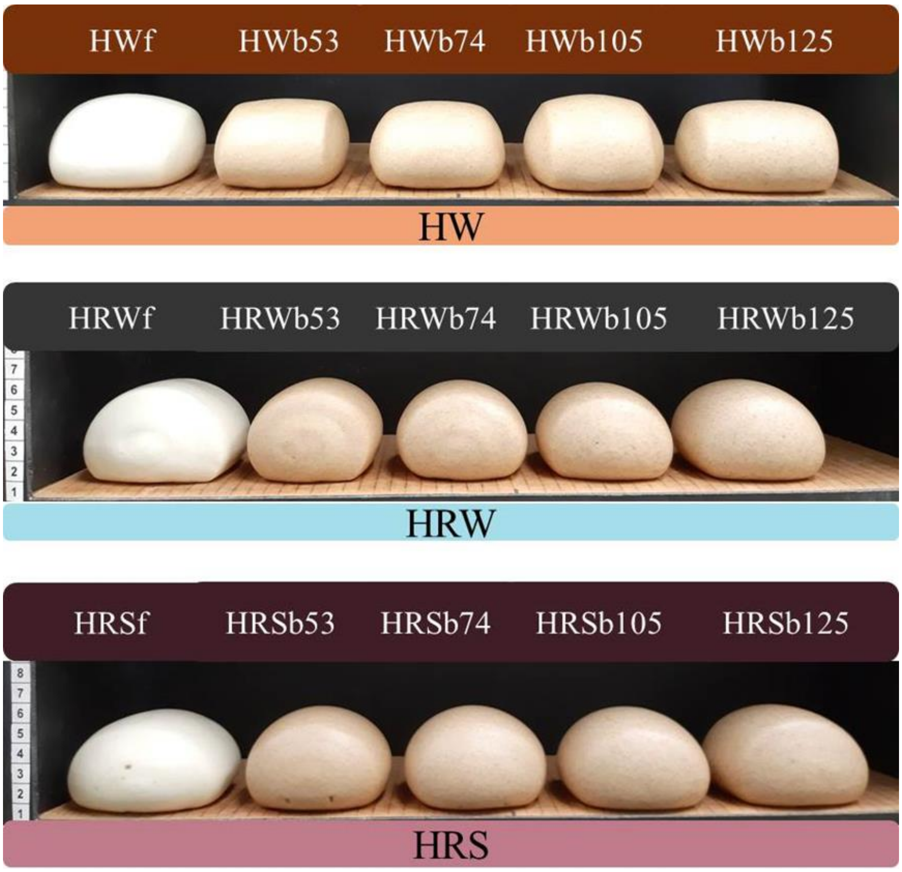

Fig. 3. Steamed breads made from refined flours and reconstituted WWF

Fig. 4. Steamed breads made from refined flours and reconstituted WWF

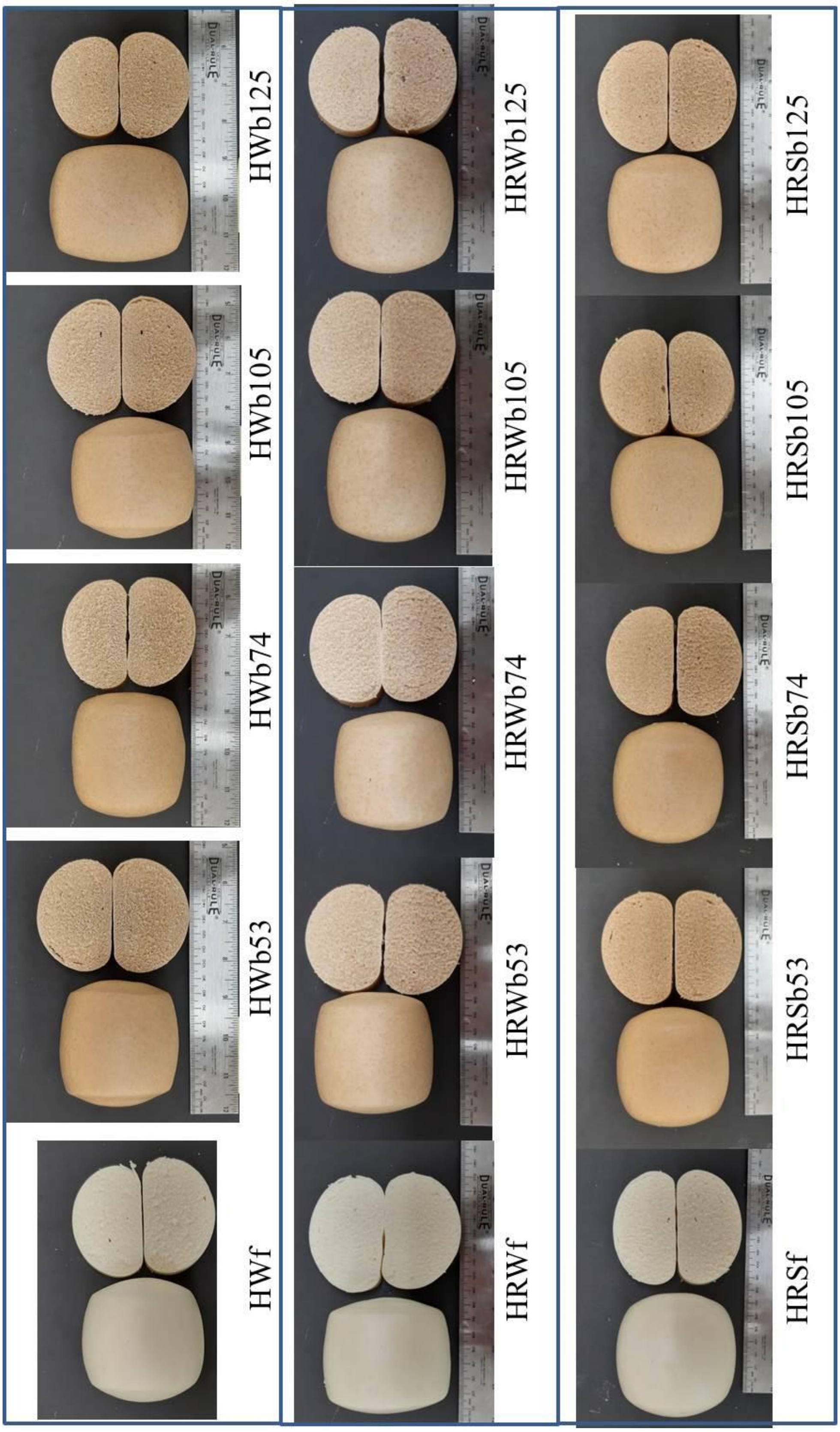

Fig. 5. Steamed breads made from refined flours and reconstituted WWF

Steamed bread color

Table 8 shows the L, a, b, and whiteness index (WI) for the steamed breads. In all cases, the reconstituted WWF L and WI were lower than those of the control flours. Smaller bran particle sizes resulted in lower L and WI values than those from larger bran particle sizes. This may be related to differences in specific volume as larger volumes tend to result in brighter, whiter color.

Table 8. Color of steamed bread made from refined flour and reconstitution WWF

	L	a	B	WI*
HWf	91.55±0.65[a]	-2.03±0.05[g]	17.55±0.10[i]	80.41±0.32[a]
HWb53	70.11±0.64[d]	6.45±0.10[cd]	24.13±0.21[e]	61.05±0.57[e]
HWb74	70.97±0.86[cd]	6.75±0.24[b]	24.58±0.47[cd]	61.36±0.97[de]
HWb105	71.75±0.24[bc]	6.05±0.08[e]	23.37±0.12[f]	62.84±0.25[c]
HWb125	68.65±1.93[e]	6.53±0.10[c]	23.50±0.31[f]	60.26±1.38[ef]
HRWf	91.12±0.47[a]	-2.19±0.03[g]	19.00±0.50[g]	78.91±0.60[b]
HRWb53	69.90±0.71[d]	7.13±0.06[a]	25.61±0.23[a]	59.84±0.41[f]
HRWb74	69.97±0.79[d]	6.84±0.15[b]	25.00±0.12[b]	60.33±0.68[ef]
HRWb105	72.06±0.87[bc]	6.38±0.11[cd]	24.37±0.19[de]	62.38±0.67[cd]
HRWb125	71.86±0.59[bc]	6.44±0.12[cd]	24.23±0.22[de]	62.31±0.54[cd]
HRSf	90.48±0.29[a]	-1.76±0.04[f]	18.59±0.33[h]	79.04±0.39[b]
HRSb53	70.77±0.79[cd]	6.83±0.16[b]	24.90±0.23[bc]	61.00±0.72[e]
HRSb74	70.27±0.59[d]	6.74±0.12[b]	24.61±0.16[b-d]	60.82±0.53[ef]
HRSb105	72.54±0.54[b]	6.32±0.13[d]	24.15±0.22[e]	62.89±0.53[c]
HRSb125	71.75±1.20[bc]	6.45±0.15[cd]	24.15±0.16[e]	62.27±0.97[cd]

n=5

Values followed by the different letters in the same column are significantly different ($P < 0.05$)

*Whiteness index (WI) = $100 - ((100 - L)^2 + a^2 + b^2)^{0.5}$

Values followed by the same letter in the same row are not significantly different ($P < 0.05$)

Steamed bread texture profile analysis

The textural characteristics of steamed breads as determined by texture profile analysis (TPA) analysis are shown in Table 9. All steamed breads from reconstituted WWF showed greater firmness and chewiness than their respective refined flours. The HRW samples displayed a trend towards increasing firmness and chewiness as bran particle size decreased and loosely aligns with specific volume trends. However, neither the HW nor the HRS groups demonstrated such a consistent trend in terms of bran particle size and texture. And while HWb125, HRWb125 and HRSb125 all showed larger specific volumes among the reconstituted WWF steamed breads, there was no significant correlation to the texture values.

Looking through a different lens, the greatest firmness was observed in HW and HRW samples. The protein content of HRSf was 15.66%. Adding bran or other materials in refined flour affects the formation of the gluten network during the dough mixing. For refined flour with lower protein content, bran has a more negative effect on the end product. It can therefore be speculated that HRS, with its naturally greater protein content and strong, extensible gluten characteristics, is more capable of overcoming the deleterious impact of brain in whole wheat steamed bread than either HW or HRW.

Table 9. Texture profile analysis of steamed breads made from refined flours and reconstituted WWF

	Firmness (g)	Springiness	Cohesiveness	Chewiness	Resilience
HWf	825.4 ± 34.5^{d}	0.8 ± 0.03^{a}	0.7 ± 0.01^{a}	457.6 ± 21.7^{d}	0.3 ± 0.01^{a}
HWb53	1694.3 ± 81.8^{b}	0.8 ± 0.02^{a}	0.6 ± 0.01^{a}	847.4 ± 35.9^{b}	0.2 ± 0.01^{a}
HWb74	1843.9 ± 85.5^{a}	0.8 ± 0.01^{a}	0.6 ± 0.03^{a}	930.9 ± 20.0^{a}	0.2 ± 0.01^{a}
HWb105	1461.3 ± 66.5^{c}	0.8 ± 0.02^{a}	0.6 ± 0.01^{a}	743.8 ± 34.3^{c}	0.2 ± 0.01^{a}
HWb125	1696.1 ± 78.8^{b}	0.8 ± 0.01^{a}	0.6 ± 0.01^{a}	851.2 ± 35.3^{b}	0.2 ± 0.01^{a}
HRWf	1138.9 ± 54.4^{d}	0.8 ± 0.03^{a}	0.7 ± 0.02^{a}	602.7 ± 30.2^{c}	0.3 ± 0.01^{a}
HRWb53	1869.9 ± 85.0^{a}	0.8 ± 0.02^{a}	0.6 ± 0.01^{a}	786.4 ± 38.3^{a}	0.2 ± 0.01^{a}
HRWb74	1626.5 ± 59.4^{b}	0.8 ± 0.02^{a}	0.6 ± 0.01^{a}	753.9 ± 19.1^{ab}	0.2 ± 0.01^{a}
HRWb105	1590.6 ± 79.0^{b}	0.8 ± 0.03^{a}	0.6 ± 0.01^{a}	731.2 ± 33.9^{b}	0.2 ± 0.01^{a}
HRWb125	1487.2 ± 62.0^{c}	0.8 ± 0.02^{a}	0.6 ± 0.01^{a}	734.6 ± 39.2^{b}	0.2 ± 0.01^{a}
HRSf	795.9 ± 39.1^{d}	0.9 ± 0.02^{a}	0.7 ± 0.01^{a}	480.7 ± 18.7^{c}	0.3 ± 0.01^{a}
HRSb53	1485.6 ± 67.0^{ab}	0.8 ± 0.02^{a}	0.6 ± 0.01^{a}	757.1 ± 26.3^{b}	0.2 ± 0.02^{a}
HRSb74	1310.3 ± 40.0^{c}	0.8 ± 0.04^{a}	0.6 ± 0.01^{a}	701.7 ± 30.2^{b}	0.2 ± 0.01^{a}

HRSb105	1541.5 ± 70.6^{a}	0.8 ± 0.01^{a}	0.6 ± 0.01^{a}	794.1 ± 20.9^{a}	0.2 ± 0.01^{a}
HRSb125	1412.2 ± 57.1^{b}	0.8 ± 0.01^{a}	0.6 ± 0.01^{a}	725.6 ± 27.0^{b}	0.2 ± 0.01^{a}

n=5 to 8

Values followed by the same letter in the same column and wheat class are not significantly different (P < 0.05)

Conclusions

In the same class of wheat, adding 15% bran with bran particle size distributions between 53µm to 125µm increased the water absorption and decreased DT and ST for HW and HRS samples. HRW did not follow the same trends as HW and HRS, likely due to differences in gluten characteristics.

The TPA test showed that adding 15% bran affects the firmness and chewiness of steamed bread, but a clear trend was not discernable across all classes. This may be related to a number of factors including wheat class, protein content and quality, and ingredient interactions in the full formula dough.

Other research has shown that smaller bran particle sizes can adversely affect bread quality. In this study, larger bran particle size distributions (105 µm and 125 µm) are recommended for whole wheat steamed bread production in order to obtain steamed breads with a larger specific volume and softer texture.

Future work

This study utilized reconstituted whole wheat flours to control variability stemming from attempting to combine different ratios of bran and shorts from the wheat classes studied. Future work should attempt to investigate whole wheat flours that contain all the bran and shorts.

Additionally, the conditions of steamed bread production were optimized and held constant throughout the study. Because there are many ways of producing steamed bread, it is recommended to optimize and study different production conditions according to their popularity in the commercial baking industry.

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