

Substituting Normal and Waxy-Type Whole Wheat Flour on Dough and Baking Properties

Induck Choi[†], Chun-Sik Kang, Young-Keun Cheong, Jong-Nae Hyun, and Kee-Jong Kim

National Institute of Crop Science, RDA, Jeonbuk 570-080, Korea

Abstract

Normal (cv. Keumkang, KK) and waxy-type (cv. Shinmichal, SMC) whole wheat flour was substituted at 20 and 40% for white wheat flour (WF) during bread dough formulation. The flour blends were subjected to dough and baking property measurement in terms of particle size distribution, dough mixing, bread loaf volume and crumb firmness. The particle size of white wheat flour was the finest, with increasing coarseness as the level of whole wheat flour increased. Substitution of whole wheat flour decreased pasting viscosity, showing all RVA parameters were the lowest in SMC40 composite flour. Water absorption was slightly higher with 40% whole wheat flour regardless of whether the wheat was normal or waxy. An increased mixing time was observed when higher levels of KK flour were substituted, but the opposite reaction occurred when SMC flour was substituted at the same levels. Bread loaf volume was lower in breads containing a whole wheat flour substitution compared to bread containing only white wheat flour. No significant difference in bread loaf volume was observed between normal and waxy whole flour, but the bread crumb firmness was significantly lower in breads containing waxy flour. The results of these studies indicate that up to 40% whole wheat flour substitution could be considered a practical option with respect to functional qualities. Also, replacing waxy whole flour has a positive effect on bread formulation over normal whole wheat flour in terms of improving softness and glutinous texture.

Key words: whole wheat flour, normal and waxy wheat, bread-making, dough property, bread quality

INTRODUCTION

Breads are important component in many Western countries, as they function mainly as a starch and an energy provider. With the recent increased consumption of breads in Asian countries as a meal and a snack, bread becomes one of the most popular foods consumed globally. Wheat (*Triticum aestivum* L.) is the most suitable crop for making yeast-leavened breads and other baked products due to its protein compositions of glutenin and gliadin that give bread dough its desirable viscoelastic properties (1).

The growing awareness of the healthy diets drives consumers to look for breads and baked products that will fit healthy everyday meals. White wheat flour is generally used to make breads, because it has high sensory qualities. However, during milling process, most of the essential nutrients and biologically active components, such as dietary fiber, minerals, and antioxidant components, are removed because those nutritionally beneficial constituents are primarily located in the wheat germ and bran layer (2). Thus, white wheat flour-processed products lack those functional bioactive compounds, whereas whole grain products do have added health benefits.

Studies relating to whole grain consumption have reported that whole grain is associated with reduced risk of type-2 diabetes, cardiovascular disease, and some types of cancer, such as colon and pancreatic cancer (3-6).

Bread's nutritional profile can be improved with substituting part of the white flour with other functional ingredients to make the bread healthier. Izydorczyk et al. (7) studied the effect of barley and barley components with higher β -glucans on the rheological properties of wheat dough. Barros et al. (8) produced tortillas from whole wheat flour and compared the quality characteristics with those from refined flour. They observed a significant improvement of the nutritional profile of tortilla products from whole wheat flour, but the physical and rheological properties differed between those products, such that the refined wheat flour doughs were more extensible and softer than whole wheat flour dough. On the other hand, Van Hung et al. (9) examined the influence of substituting white flour with whole waxy wheat flour on bread dough and qualities of breads. They suggested that whole waxy flour could be used for bread making to improve nutritious quality of bread for health benefits.

[†]Corresponding author. E-mail: ichoi829@korea.kr
Phone: +82-63-840-2258, Fax: +82-63-840-2116

Upon consumer's expectations concerning bread, higher sensory quality is one of important factors that influence consumer's acceptability. In bread-making, using whole grain flour produced less favorable breads due to bran and germ that deteriorate the rheological properties of dough and bread. Thus, the inferior quality of whole grain bread has been an issue and research has been focused on enhancing the quality of whole wheat bread and baked products. The objectives of this study were to substitute partly white wheat flour with normal and waxy-type whole wheat flour and to investigate their effects on bread quality in terms of dough properties and some specific bread quality characteristics.

MATERIALS AND METHODS

Materials

Normal wheat cultivar 'Keumkang' and waxy-type wheat cultivar 'Shinmichal' were developed in the National Institute of Crop Science, RDA, and grown during 2010~2011 growing season. After harvesting, the wheat kernels were cleaned and ground using a hammer mill (Laboratory Mill 3100, Pertent Co. Ltd., Huddinge, Sweden) equipped with 0.5 mm screen. Commercial white wheat flour was purchased in a local market and used as the base flour. With the white flour as base flour, the flour blends were prepared by substituting some of the white flour with normal and waxy-type whole wheat flour at levels of 20 and 40%.

Particle size and pasting properties of the composite flour

The particle size distribution of composite flour (4~5 g) was determined using a multi-wavelength particle size analyzer (LS 13 320, Beckman Coulter, Miami, FL, USA) with a dry powder attachment. The measurement parameters include mean particle diameter, median particle diameter, and particle diameter at cumulative 10% (D10), 50% (D50) and 90% (D90) of the portion of the sample flour analyzed by the instrument. Starch pasting properties were measured by a Rapid Visco Analyzer (RVA-4, Newport Scientific Pty, Ltd., Warriewood, Australia) in accordance with the AACC Official Method 61-02. Flour samples were placed in a clean RVA test canister, and 25 mL distilled water was carefully dispensed into the canister, to which a paddle was placed. At the beginning of test, high speed mix (960 rpm) was used to disperse the sample for the initial 10 s, followed by moderate application for shear (160 rpm) for the remainder of 12.5 min test period. Temperature profiles were equilibrating at 50°C for 1.0 min, ramping up to 95°C in 4.8 min, holding at 95°C until 7.5 min, ramping down to 50°C

at 11.0 min, and holding at 50°C until 12.5 min. Pasting parameters were peak viscosity (PV), trough viscosity (TV), breakdown (BD), final viscosity (FV), and peak temperature (Ptemp). The viscosity was read directly from the RVA and reported in arbitrary rapid visco units (RVU). All viscosity measurements were conducted in triplicate.

Bread making

Test breads were baked using 100 g composite flour according to a basic straight dough method of AACC Official Method 10-10A. White wheat bread, as a control, was made with commercial white flour. Bread formula consisted of wheat flour (100 g), sugar (5 g), salt (2 g), shortening (3 g), non-fat dry milk (4 g), active dry yeast (2 g), and water (variable). The optimum water absorption and mixing time were adjusted by the 10 g mixograph (National Mfg. Co., Lincoln, NE, USA) determination (AACC 54-40A). Other than the flour, all ingredients and their amounts in the formula were the same for white wheat bread as well as whole wheat-substituted breads. Bread dough was prepared using a 100 g pin-type mixer (National Mfg. Co), then fermented in a cabinet fermenter (Model FP201, Daeyoung Co., Seoul, Korea) at 30°C and 85% relative humidity. A dough molder (Model DYM 2001, Daeyoung Co., Seoul, Korea) was used for sheeting and molding purpose. After proofing, baking was done in an electrical deck oven (DYM FDO 7102, Daeyoung Co.) at top 210°C and bottom 205°C for 24 min. The baked breads were cooled at room temperature for 2 hr for further analysis. For the pH measurement of bread dough, 10 g of dough was dissolved completely in 35 mL of distilled water, and the value of pH was determined.

Baking and bread properties

Water content of bread crumbs was determined with 1 g of bread crumb using a moisture analyzer (Sartorius, Bohemia, NY, USA). Bread loaf volume was measured with a bread loaf volumeter (National Mfg. Co.) using rapeseed displacement method. Specific volume of bread was determined as the ratio of the loaf volume to its weight. Bread crumb firmness was measured using a texture analyzer (Model TA-XT2, Stable Micro System Ltd., Haslemere, UK). The bread loaves were sliced into 1.3 cm thick and used immediately for bread crumb firmness measurement. Two breads slices were placed on a flat metal plate, and compressed to a total compression of 40% using a flat aluminum plunger with a diameter of 35 mm. The maximum peak force (g) in compression was recorded as the firmness of bread crumb. The whole procedure was repeated on 5 different sets of bread sli-

ces, and the firmness values were averaged. The color parameters of Hunter's L (lightness), a (redness) and b (yellowness) values of the bread crumb were measured using a color difference meter (Color JS-55, Color Technology System Co., Tokyo, Japan) in triplicate.

Statistical analysis

All data were analyzed using SAS statistical software (Version 9.1, SAS Institute Inc., Cary, NC, USA). Analysis of variance (ANOVA) was performed to observe the substitution effects of normal and waxy-type whole wheat flour on dough and baking properties. The significance of differences was analyzed by Fisher's LSD multiple comparison

RESULTS AND DISCUSSION

Pasting properties

The RVA pasting viscosity of white flour and whole wheat substituted flour are presented in Table 1. The flour samples were white wheat flour (WF) and whole wheat substituted flour with cvs. Keumkang (KK) and Shinmichal (SMC) at 20% (KK20, SMC20) and 40% (KK40, SMC40). The ANOVA (*F*-value) shows significant differences in RVA parameters among flour blends, indicating differences in their behavior during heating and cooling of the RVA analysis. White flour had the highest peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BD), and final viscosity (FV) followed by the KK20. The viscosity of SMC40 exhibited the lowest values in PV, TV, BD, FV, and SB viscosity. There was no significant difference in pasting temperature among flour samples. Results suggest that the partial substitution of whole wheat flour decreased the pasting viscosity, which might be due to the reduced starch contents because of the replacement of white flour with whole wheat flour. In addition, the proteins in whole wheat flour could also be a factor affecting the pasting viscosity (10,11). The PV value related to starch swelling capacity is associated with BD and SB viscosity. During RVA testing, starch granules of the flours in excess water, which is heated to high temperature and subjected to mechanical

shear stress, are disrupted, resulting in amylose leaching out and granule alignment, which cause a decrease in viscosity associating with BD viscosity (12). In general, higher PV values are related to high BD viscosity, which is related to starch swelling capacity. Higher BD values could imply lower hot starch paste stability. White flour had the highest PV (136.4 RVU) and BD (53.1 RVU) followed by the KK20 flour blend (PV of 123.1 and BD of 47.0). The lowest PV and BD viscosity was found in the SMC40 with values of 89.3 and 33.2 (RVU), respectively. During the cooling periods, the starch molecules (especially linear chains, such as amylose) are re-associated, and starch molecules are aligned to form a gel structure. This phase is referred to SB viscosity, which is related to starch retrogradation (13). The SB viscosity values were the highest in the KK40 (25.9 RVU) followed by KK20 and WWF (22.2 and 21.6, respectively). The lowest SB viscosity from the SMC40 (15.0 RVU) indicates lower starch retrogradation and syneresis.

Particle size distribution and dough properties

The particle size distribution of composite flour and dough mixing properties are presented in Table 2. The ANOVA results indicate that substituting normal and waxy whole wheat flour at 20 and 40% levels had a significant effect on particle size distribution and dough mixing time. The mean diameter of particle size was the lowest in WF at 67.9 μm , whereas the highest in SMC40 at 147.3 μm . Increasing whole wheat flour from 20 to 40% increased the coarse particle size distribution in the composite flour. From the diameter of particle size at cumulative 10% (D10), 50% (D50), and 90% (D90), it was observed that waxy-type whole wheat flour resulted in coarser particle size compared to normal whole flour.

With the respect to optimum water absorption and mixing time determined by 10 g mixograph analysis, an increase in whole wheat flour from 20 to 40%, regardless of whether it was normal or waxy-type, increased water absorption from 64% to 65%, respectively. Mixographs

Table 1. Pasting properties of the composite flour of whole and white wheat flour

(unit: RVU)

Wheat flour	Peak V.	Trough V.	Breakdown V.	Final V.	Setback V.	Pasting temp.
WF	136.4 \pm 2.4 ^a	83.2 \pm 3.5 ^a	53.1 \pm 1.6 ^a	158.0 \pm 3.8 ^a	21.6 \pm 2.1 ^b	65.7 \pm 0.8 ^a
KK20+WF80	123.1 \pm 3.4 ^b	76.1 \pm 3.4 ^b	47.0 \pm 0.8 ^b	145.2 \pm 1.1 ^b	22.2 \pm 2.3 ^{ab}	65.7 \pm 2.8 ^a
KK40+WF60	109.4 \pm 1.8 ^c	68.1 \pm 1.4 ^c	41.3 \pm 1.3 ^d	135.4 \pm 1.9 ^c	25.9 \pm 1.7 ^a	67.6 \pm 0.5 ^a
SMC20+WF80	110.9 \pm 2.6 ^c	67.4 \pm 1.6 ^c	43.6 \pm 1.1 ^c	128.1 \pm 1.6 ^d	17.1 \pm 2.7 ^c	67.1 \pm 1.2 ^a
SMC40+WF60	89.3 \pm 2.0 ^d	56.1 \pm 0.9 ^d	33.2 \pm 1.2 ^e	104.3 \pm 0.6 ^e	15.0 \pm 1.7 ^c	67.8 \pm 0.4 ^a
F-value	144.49 ^{***}	53.47 ^{***}	106.00 ^{***}	279.90 ^{***}	12.51 ^{***}	1.43

^{a-c}Values with different letters in the same column are significantly different at $p < 0.05$.

^{***}Significant at $p < 0.01$.

KK (wheat cv. Keumkang), SMC (wheat cv. Shinmichal), WF (white wheat flour).

(Fig. 1) revealed that dough mixing time was different depending on the wheat cultivars and the levels of whole wheat substitution. The dough mixing time of WF was 4.20 (min), whereas replacing with KK flour from 20 to 40% increased dough mixing time to 4.40 and 5.10 (min), respectively. In contrast to KK flour, substitution with SMC flour from 20 to 40% decreased mixing time to 4.10 and 3.40 (min), respectively. In general, the dough

pH for yeast-leavened breads is known to be around pH 5.0~5.5. As shown in Table 2, the pH of all bread dough formulation ranged from 5.33~5.61, which are all within the normal range.

Baking properties

The end-use qualities of breads were observed by measuring bread crumb moisture content, loaf volumes, and the firmness and color of bread crumb shown in

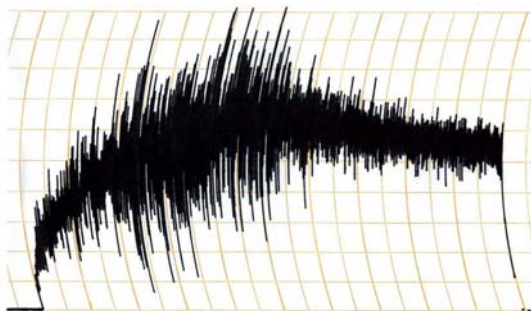
Table 2. Particle size distribution of the composite flour with normal and waxy-type whole wheat flour and the dough properties

Breads	Particle size distribution					Dough properties		
	Mean	Median	D10	D50	D90	Water abs. (%)	Mixing time (min)	pH
WF	67.9±0.9 ^d	66.3±1.0 ^c	15.9±0.3 ^a	66.3±1.0 ^c	122.9±1.2 ^d	64	4'20"	5.33±0.03 ^d
KK20+WF80	95.7±5.2 ^c	72.8±1.2 ^b	16.5±0.3 ^a	72.8±1.2 ^b	169.6±8.4 ^{cd}	64	4'40"	5.45±0.04 ^c
KK40+WF60	121.8±0.2 ^b	79.9±0.4 ^a	16.3±0.4 ^a	79.9±0.4 ^a	270.9±2.4 ^b	65	5'10"	5.55±0.02 ^b
SMC20+WF80	114.0±6.9 ^b	71.9±1.3 ^b	14.4±0.3 ^b	71.9±1.3 ^b	225.2±51.8 ^{bc}	64	4'10"	5.50±0.01 ^{bc}
SMC40+WF60	147.3±4.7 ^a	79.3±1.3 ^a	13.4±0.1 ^c	79.3±1.3 ^a	447.9±19.0 ^a	65	3'40"	5.61±0.01 ^a
ANOVA (F-value)	89.85 ^{***}	52.36 ^{***}	49.47 ^{***}	52.36 ^{***}	50.78 ^{***}	—	—	38.85 ^{***}

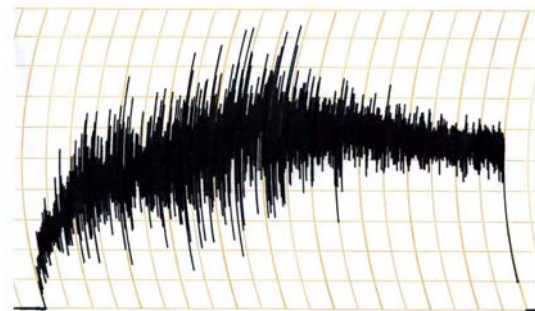
^{a-d}Values with different letters in the same column are significantly different at $p < 0.05$.

^{***}Significant at $p < 0.01$.

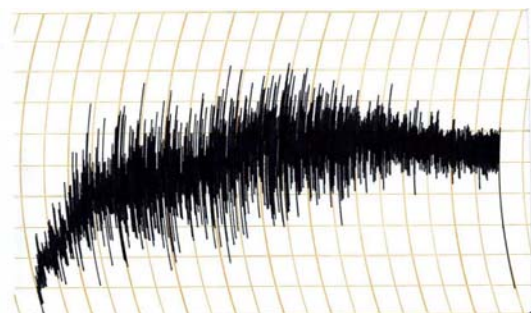
KK (wheat cv. Keumkang), SMC (wheat cv. Shinmichal), WF (white wheat flour).



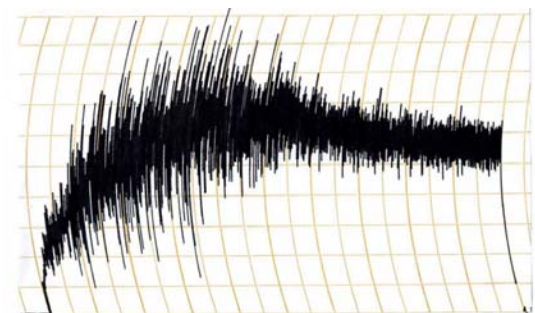
White wheat flour



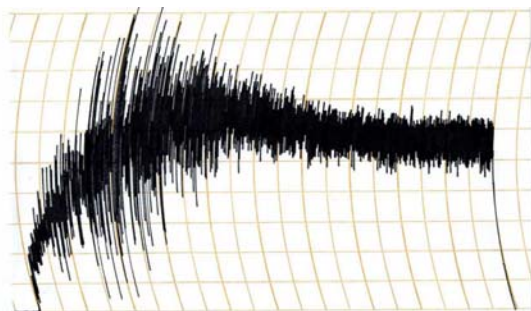
KK 20% substituted flour



KK 40% substituted flour



SMC 20% substituted flour



SMC 40% substituted flour

Fig. 1. Mixograms of white wheat flour and whole wheat substituted flour with "Keumkang" (20 and 40%) and "Shinmichal" (20 and 40%).

Table 3 and Table 4. The data indicate there was no significant difference among the bread samples in bread crumb moisture content. The specific volume of WF bread was higher than those breads from whole wheat substituted flours. Regarding normal and waxy-type whole wheat flour and also the levels of substitution, there was no statistically significant difference ($p < 0.05$) in loaf volume, although the measured values for bread loaf volume from blends flour with 20% substitution was lower than those from 40% substituted flour. Compared to WF bread, the lower bread loaf volume from the flour blends might be due to the increased dietary fiber contents present in bran layer. The fiber and bran particles in the substituted flour might interrupt the continuities and homogeneities of protein strands, and decrease gluten strength, causing less gas-holding capacity (14,15). Van Hung et al. (9) explain that a high amount of dietary fiber might dilute the gluten protein and interfere with optimal gluten matrix formation during dough fermentation and bread baking. On the other hand, Lai et al. (16) studied the effects of wheat bran properties on bread quality and report that the source of bran and the particle size of bran would be the major factors to influence bread loaf volume, suggesting that fine particles of bran resulted in higher bread loaf volume.

The functional characteristics of waxy wheat flour (white and whole flour) for bread-making qualities have been investigated in some studies. Van Hung et al. (9) used whole wheat and partially whole waxy wheat flour

for bread formulation, and observed that bread volume of whole wheat was significantly lower than those breads made from partially substituted flours. They also suggest that the substitution up to 50% of whole waxy flour would be suitable for bread-making based on consumer acceptability of the quality and the benefits of whole wheat foods. In addition, studies conducted by Hayakawa et al. (17) and Lee et al. (18) report that incorporation of waxy wheat flour in bread formulation could retain more moisture in bread crumbs and retard bread staling, resulting in the extension of bread shelf life. Morita et al. (19) also report that substituting white wheat flour with waxy-type flour for bread formula could contribute to the delay of bread staling due to lower retrogradation tendency.

Table 4 presents the firmness and color of bread crumb made from WF and the KK and SMC flours. The ANOVA shows that the firmness and color of bread crumbs were significantly influenced by wheat cultivars and the substitution levels. The crumb firmness from KK40 bread was the highest, followed by KK20 and SMC40 bread, then by SMC20 and WF bread. Compared to normal whole flour, substitution with some waxy whole flour could produce breads with softer bread crumb texture. The results in present study were consistent with the previous studies (16,17), reporting that waxy wheat flour could improve the end-use bread qualities in terms of bread softness and shelf life extension. As expected, bread crumb color measured with Hunter's

Table 3. Baking properties of breads from the composite flour with normal and waxy-type whole wheat flour

Breads	Water content (%)	Loaf wt. (g)	Loaf vol. (cm ³)	Specific vol. (cm ³ /g)
WF	44.6 ± 1.5 ^a	143.8 ± 0.8 ^c	783.3 ± 14.4 ^a	5.4 ± 0.1 ^a
KK20+WF80	45.3 ± 0.8 ^a	145.2 ± 1.1 ^{bc}	700.0 ± 35.4 ^{ab}	4.8 ± 0.2 ^b
KK40+WF60	43.3 ± 0.1 ^a	147.4 ± 0.9 ^a	650.0 ± 35.4 ^b	4.4 ± 0.3 ^b
SMC20+WF80	43.4 ± 0.2 ^a	147.1 ± 0.9 ^{ab}	700.0 ± 35.4 ^{ab}	4.8 ± 0.2 ^b
SMC40+WF60	43.6 ± 0.1 ^a	147.9 ± 0.3 ^a	637.5 ± 53.0 ^b	4.3 ± 0.4 ^b
ANOVA (F-value)	2.52	10.52 ^{***}	7.2 ^{**}	9.83 ^{***}

^{a-c}Values with different letters in the same column are significantly different at $p < 0.05$.

Significant at ^{***} $p < 0.01$ and ^{**} $p < 0.05$, respectively.

KK (wheat cv. Keumkang), SMC (wheat cv. Shinmichal), WF (white wheat flour).

Table 4. Bread crumb firmness and color

Breads	Firmness (g)	Color		
		L	a	b
WF	356.5 ± 55.6 ^c	77.9 ± 0.6 ^a	2.2 ± 0.1 ^d	13.6 ± 0.4 ^e
KK20+WF80	460.4 ± 19.1 ^b	73.9 ± 0.5 ^b	3.9 ± 0.1 ^c	15.9 ± 0.0 ^d
KK40+WF60	613.8 ± 71.3 ^a	71.9 ± 0.9 ^c	5.6 ± 0.1 ^b	18.5 ± 0.1 ^b
SMC20+WF80	290.3 ± 20.7 ^c	72.0 ± 0.5 ^c	5.5 ± 0.2 ^b	16.8 ± 0.1 ^c
SMC40+WF60	482.5 ± 52.8 ^b	65.8 ± 0.3 ^d	7.8 ± 0.3 ^a	19.5 ± 0.4 ^a
ANOVA (F-value)	21.78 ^{***}	114.83 ^{***}	259.86 ^{***}	149.79 ^{***}

^{a-e}Values with different letters in the same column are significantly different at $p < 0.05$.

^{***}Significant at $p < 0.01$.

KK (wheat cv. Keumkang), SMC (wheat cv. Shinmichal), WF (white wheat flour).

L, *a* and *b* shows that substituting whole wheat flour decreased the lightness of bread, with the highest *L*-value seen in WF bread, which was 77.9. The redness (*a*-value) and yellowness (*b*-value) was significantly increased by increasing the level of whole wheat flour.

With respect to a higher awareness of a healthy lifestyle, bakery products with whole wheat flour are becoming more important in the baking industry. Thus, normal and waxy-type whole wheat flour were partially substituted for white wheat flour to explore practical applications for bread-making. Bread loaf volume was lower in breads containing a whole wheat flour substitution compared to bread containing only white wheat flour. But, there was no significant difference in bread loaf volume regardless of the type of whole wheat flour used or the level of substituting up to 40%. On the other hand, the results in the present study demonstrated that using waxy whole flour has positive effects on pan-bread formulation in terms of improving bread softness. Using whole wheat flour has various physiological health benefits because of its functional components, such as higher dietary fiber, mineral and proteins. Also, waxy whole wheat flour could contribute to enhancing the shelf-life of breads. Thus, it is assumed that substituting whole wheat flour up to 40% could be practical with respect to increasing bread's functional qualities.

ACKNOWLEDGMENTS

The authors acknowledge the financial support from the National Institute of Crop Science (NICS) of the Rural Development Administration (RDA).

REFERENCES

- Morita N, Fujita S, Domon E, Ando H, Mitsunaga T. 1998. Effect of the substitution of waxy-barley flour on the viscoelastic properties of wheat dough and bread making. *J Appl Glycosci* 45: 385-391.
- Steinfurth D, Koehler P, Seling S, Mühling KH. 2012. Comparison of baking tests using wholemeal and white wheat flour. *Eur Food Res Technol* 234: 845-851.
- de Munter JSL, Hu FB, Spiegelman D, Franz M, van Dam RM. 2007. Whole grain, bran, and germ intake and risk of type 2 diabetes: A prospective cohort study and systematic review. *PLoS Medicine* 4: e261.
- Jensen MK, Koh-Banerjee P, Hu FB, Franz M, Sampson L, Grønbaek M, Rimm EB. 2004. Intakes of whole grains, bran, and germ and the risk of coronary heart disease in men. *Am J Clin Nutr* 80: 1492-1499.
- Larsson SC, Giovannucci E, Bergkvist L, Wolk A. 2005. Whole grain consumption and risk of colorectal cancer: A population-based cohort of 60,000 women. *British J Cancer* 92: 1803-1807.
- Chan JM, Wang F, Holly EA. 2007. Whole grains and risk of pancreatic cancer in a large population-based case-control study in the San Francisco Bay Area, California. *Am J Epidemiol* 166: 1174-1185.
- Izydorczyk MS, Hussain A, MacGregor AW. 2001. Effect of barley and barley components on rheological properties of wheat dough. *J Cereal Sci* 34: 251-260.
- Barros F, Alviola JN, Rooney LW. 2010. Comparison of quality of refined and whole wheat tortillas. *J Cereal Sci* 51: 50-56.
- Van Hung P, Maeda T, Morita N. 2007. Dough and bread qualities of flours with whole waxy wheat flour substitution. *Food Research International* 40: 273-279.
- Batey IL, Curtin BM. 2000. The effects on the pasting viscosity of starch and flour of different operating conditions for the Rapid Visco Analyzer. *Cereal Chem* 77: 754-760.
- Morris C, King GE, Rubenthaler GL. 1997. Contribution of wheat flour fractions to peak hot paste viscosity. *Cereal Chem* 74: 147-153.
- Ragaei S, Abdel-Aal EM. 2006. Pasting properties of starch and protein in selected cereals and quality of their food products. *Food Chem* 95: 9-18.
- Gray D, Abdel-Aal EM, Seetharaman K, Kakuda Y. 2010. Difference in viscosity and textural properties of selected barley cultivars as influenced by pearling and cooking. *Food Chem* 120: 402-409.
- Camire ME. 2004. Technological challenge of whole grains. *Cereal World* 49: 20-22.
- Gan Z, Angold RE, Williams MR, Ellis PR, Vaughan JG, Galliard T. 1990. The microstructure and gas retention of bread dough. *J Cereal Sci* 12: 15-24.
- Lai CS, Hoseney RC, Davis AB. 1989. Effects of wheat bran in breadmaking. *Cereal Chem* 66: 217-219.
- Hayakawa K, Tanaka K, Nakamura T, Endo S, Hoshino T. 2004. End use quality of waxy wheat flour in various grain-based foods. *Cereal Chem* 81: 666-672.
- Lee MR, Swanson BG, Baik BK. 2001. Influence of amylase content on properties of wheat starch and bread-making quality of starch and gluten blends. *Cereal Chem* 78: 701-706.
- Morita N, Maeda T, Miyazaki M, Yamamori M, Miura H, Ohtsuka I. 2002. Effect of substitution of waxy-wheat flour for common flour on dough and baking properties. *Food Sci Technol Res* 8: 119-124.

(Received August 9, 2012; Accepted September 12, 2012)