

Staling of Bread as Affected by Waxy Wheat Flour Blends

Monisha Bhattacharya,^{1,2} Sofia V. Erazo-Castrejón,¹ Douglas C. Doehlert,^{1,3} and Michael S. McMullen⁴

ABSTRACT

Cereal Chem. 79(2):178–182

Crumb softness and improved shelf life of bread is often achieved by incorporating expensive shortenings in the formulation. We hypothesized that similar results could be achieved by blending bread wheat flour with waxy (low amylose) durum wheat flour. White pan bread was baked from 10, 20, and 30% waxy durum wheat flour composites and evaluated for loaf volume and crumb firmness over a period of 0, 3, and 5 days. The loaf volumes were not affected by the waxy flour blends. However, as staling progressed over 3–5 days, significant firming of crumb was observed in the control sample compared with loaves containing waxy flour.

The firmness was inversely proportional to the level of waxy flour used in the blend. A 20% waxy wheat flour blend was optimal in retarding staling while producing bread quality comparable with the control. It was further established that bread made with 20% waxy flour gave lower firmness values after 5 days of storage in comparison to bread made with 3% shortening. These results suggest that 20% waxy wheat flour could substitute for use of shortening to achieve desirable crumb softness and to retard staling upon storage.

Staling of baked goods results in considerable losses for bakers and supermarkets, and speculation flourishes on the possible use of waxy wheat to extend shelf life of baked goods (Graybosch 1998). Bread staling refers to changes in the crumb other than those resulting from the action of spoilage organisms, which decreases consumer acceptance of bakery products. It is usually characterized by toughening of the crust, firming of the crumb, loss of moisture and flavor, and a corresponding loss in product freshness (Hoseney 1994). Reduction in crumb softness over time (firming) is an important manifestation of staling and is often used to monitor the staling process, both by consumers and researchers. It is well established that various flour components have an influence on the rate of bread staling. Kim and D'Appolonia (1977) attributed staling to the formation of a protein-starch complex, with a subsequent dilution of the starch fraction. High protein content has been associated with initial crumb softness and slow firming of bread with time (Maleki et al 1980; Callejo et al 1999). Michniewicz et al (1992) suggested that flour pentosans exerted a reducing effect on bread staling rate by interacting with the gluten to form hydrated film networks, thereby increasing the water absorption of dough, which in turn contributed to the soft texture of bread crumb. A higher water absorption level results in a softer crumb and a slower rate of bread firming (Rogers et al 1988). Piazza and Masi (1995) concluded that it was more important to prevent moisture dehydration after baking than to increase the initial moisture content of the bread.

Staling in pan bread depends primarily on a change in the structure of starch from an amorphous structure to a partially crystalline state (Thomas and Atwell 1997). Starch suspensions retrograde on standing to precipitate the amylose, which is one explanation of the phenomenon of staling (Hug-Iten et al 1999). Others have explained staling of bread in terms of the amylopectin chains in starch associating to cause a greater rigidity of the bread crumb that is characteristic of stale bread (Krog et al 1989). The amount of amylose affects many of the physicochemical properties of starch because it has the ability to form a firm gel on cooking and cooling. Conversely, amylopectin slows gel formation due to its tumbleweed-like structure, and the resultant gel is soft and gummy.

When starch is composed exclusively of amylopectin, it is referred to as waxy, and it exhibits low initial pasting temperature, high clarity of paste, low syneresis, and high resistance to retrogradation (Kiri-

buchi-Otobe et al 1998). Hayakawa et al (1997) compared the structural and functional properties of starches isolated from waxy and normal hexaploid wheat using X-ray diffractometry and differential scanning calorimetry (DSC). Waxy starch had somewhat higher crystallinity and displayed a greater resistance to retrogradation. Yasui et al (1999) observed that the amylopectin structures of three different waxy wheat lines were similar to those of nonwaxy parent lines, although the apparent amylose and lipid content of the waxy starch was much lower than that of the parents. They suggested that waxy wheat would assist in retarding the staling process of baked products. Graybosch (1998) reported that waxy wheat starches have a higher water binding capacity than normal starches, and might therefore be used to extend the shelf life of baked goods without a concomitant dilution of wheat gluten. He further stated that the development of waxy wheat flour could be widely applied in frozen foods, retort-packed foods, as well as in many nonfood industries.

Researchers throughout the world have tried to retard staling through the addition of ingredients such as α -amylases (Morgan et al 1997; Champenois et al 1999), maltodextrins (Gerrard et al 1997; Defloor and Delcour 1999), lipids (Collar et al 1998), surfactants (Rao et al 1992; Faheid and Ragab 1996; Stauffer 2000), and shortenings or emulsifiers (Armero and Collar 1998; Forssell et al 1998; Genc et al 2000). Most of these additives exert a favorable effect on the keeping quality of bread by either increasing the water retention of the dough (Lee et al 1998) or by forming a complex with starch (De Stefanis et al 1977). While this approach has been successful and is widely used in the baking industry, it would be highly desirable to develop a method for reducing the staling of bakery goods without the need for such expensive additives. Various cereal starches and flours such as waxy barley (Ghiasi et al 1984; Inagaki and Seib 1992; Morita et al 1998; Toufeilli et al 1999), durum wheat (Boyacıoğlu and D'Appolonia 1994), oat (Zhang et al 1998), and sorghum (Hugo et al 2000) have been successfully incorporated with bread wheat flour to retard staling. The objectives of this present study were to: 1) test the effect of waxy durum flour in retarding staling and crumb firming over time; 2) determine the optimum level of waxy flour for blending with a strong bread wheat flour to produce a good quality bread; and 3) compare the texture conferred by the addition of waxy flour with that obtained by the use of a shortening.

MATERIALS AND METHODS

Wheat Samples

A hard red spring (HRS) wheat cultivar, Trenton, was used as a base flour to which two experimental lines of waxy durum flour was added at levels of 10, 20, and 30%, and these composites were used for baking bread. Trenton was selected for its strong protein mixing characteristics and superior breadbaking properties so as to mini-

¹ Department of Cereal and Food Sciences, North Dakota State University, Fargo, ND 58105.

² Corresponding author. E-mail address: Monisha_Bhattacharya@ndsu.nodak.edu
Phone: 701-231-7737. Fax: 701-231-7723.

³ USDA-ARS Wheat Quality Laboratory, NDSU, Fargo, ND 58105.

⁴ Department of Plant Sciences, NDSU, Fargo, ND 58105.

mize the possible effects of gluten dilution. Waxy durum flour was used in this study because of the unavailability of advanced waxy hexaploid wheat lines. Waxy durum was derived from an initial cross of the partial waxy (A and B-genome) hard red winter wheat 'Ike' and durum wheat 'Ben' through backcrossing. Ben was used as the durum parent due to its widespread use in the durum-growing region of the Northern Great Plains. Plants heterozygous for the waxy-null trait in both genomes (A and B) were selected by iodine staining of the pollen. In heterozygous plants, the waxy trait is expressed in one out of four pollen grains. Heterozygous plants were backcrossed to Ben, where Ben was the maternal parent. After four generations of backcrosses, full waxy seeds were derived from selfed heterozygous F1 plants, and were identified by iodine staining of half seeds. The two waxy lines used in this study were siblings full waxy lines derived from the fourth backcross to the recurrent durum parent Ben and will be referred to as Waxy1 and Waxy2 in this study. These lines had similar functional and quality characteristics. Due to limited sample availability, only Waxy1 was used in the first part of the study, which involved determining an optimum ratio of waxy blend that would produce bread of desirable quality. Once an optimum level was established, Waxy2 was used for comparing the effects of shortening and blended waxy flour on bread staling.

The genotypes were tempered to 15.5% moisture for 24 hr and milled into straight-grade flour on a Buhler laboratory mill. All the flour samples were stored in plastic bags and kept at room temperature for one week to condition the flour before further testing.

Proximate Analysis and Rheological Properties of Flours

The moisture content of the flours was determined using Approved Method 44-15A (AACC 2000) for an air oven. Protein content (14% mb) of the flours was determined using AACC Approved Method 46-30 combustion method with a nitrogen analyzer (Leco FP428, St. Joseph, MI). Rheological properties of the flour doughs were determined with a Brabender farinograph according to AACC Approved Method 54-21. Parameters recorded were water absorption of flour (14% mb), mixing time (time between the addition of water and development of maximum consistency of the dough), and mixing tolerance (the time in minutes that the farinogram remains horizontal on the 500 BU line). Starch damage (%), amylose content (%), and α -amylase activity (CU/g) of flour, were determined using enzymatic digestion assay kits (Megazyme International, Wicklow, Ireland). All analyses were made in triplicate and reported on an as-is basis.

Pasting Profile Determination

Pasting profiles were studied using a Rapid Visco Analyser (RVA) model 3D (Newport Scientific, Narrabeen, Australia) in 1 mM AgNO₃ to eliminate α -amylase activity (Bhattacharya and Corke 1996). Flour (3.5 g, db) was weighed in a canister, to which 25 g of AgNO₃ solution was added. A standardized heating and cooling cycle was employed according to Bhattacharya et al (1997). Parameters recorded were peak viscosity (PV), hot paste viscosity (HPV), breakdown (PV - HPV), cold paste viscosity (CPV), and setback (CPV - HPV). All measurements were replicated twice and the results were reported in Rapid Visco units (RVU).

Texture Analysis

The texture of the gel formed after cooking a wheat flour-water slurry is central to its functionality and is a fairly accurate indicator of how a wheat sample would influence the final product. After the RVA cycle, the stirring paddle was discarded, and the whole meal paste was kept at room temperature overnight for gelation to take place. The gel formed was subjected to texture profile analysis (TPA) using a texture analyzer (Stable Microsystems TA-XT2) (Bhattacharya et al 1997). A standard two-cycle program was used to compress the gel for a distance of 10 mm at a crosshead speed of 30 mm/min using a 7-mm cylindrical probe with a flat end. From the force-time curve obtained, textural parameters of hardness and

firmness (maximum force on cycle 1), and adhesiveness (total negative area in cycle 1) were automatically computed using the data processing software supplied with the instrument.

Breadbaking Procedures

A straight-dough procedure based on Approved Method 10-09 (AACC 2000) was used to evaluate the effect of 10, 20, and 30% waxy durum flour on the physical properties and keeping quality of bread. All samples were mixed to optimum development until a thin membrane was formed and could be seen when stretched. The water added to form optimum dough was calculated as the water absorption of flour obtained on the farinograph minus 1.5%, which resulted in better machinability and reduced stickiness for moulding and sheeting. The baking formula (flour basis) was flour (14% mb) 100.0 g, sugar 5.0 g, salt 2.0 g, shortening 3.0 g (except when evaluating the baking performance of control and waxy flours without shortening), vacuum-packed yeast 1.0 g, ammonium phosphate monobasic 0.1 g, fungal α -amylase (17 SKB units, American Ingredients, Co., Kansas City, MO), and 20 ppm of ascorbic acid. A two-step punching procedure was adopted using 180 min of fermentation. All doughs were proofed at 30°C for 55 min at 85% rh before baking. Dough pieces were baked at 220°C for 25 min. Bread loaves were allowed to cool for a minimum of 60 min before further testing.

Bread Quality Evaluations

The volume of each loaf was measured by rapeseed displacement 1 hr after bread was removed from oven. Crumb grain and texture, crumb color, crust color, and symmetry were evaluated by visual comparison to a standard by an experienced baker, under a constant illumination source. Each bread loaf was scored by an experienced baker for grain and texture, and color, using a scale 1 to 10, with 10 being the best score. For the staling study, the loaves were placed in Ziploc bags, stored at room temperature, and evaluated for firmness, enthalpy changes, and moisture loss on day 0, 3, and 5. The central slices from each loaf were used to determine firmness with a texture analyzer (TA-XT2, Texture Technologies) according to Approved Method 74-09 (AACC 2000). Crumb moisture was determined as in flour but including an air-drying step before the conventional air-oven drying. To evaluate starch recrystallization, crumb samples taken from each treatment were frozen and lyophilized. The dried crumb (2.89–3.14% moisture) was ground in an ultracentrifugal mill (model ZM1, Brinkmann Instruments Co., Westbury, NY). Differential scanning calorimetry (DSC-7, Perkin-Elmer Corp., Norwalk, CT) was used to evaluate the enthalpy changes (ΔH) in the crumb over time, which is a measure of starch retrogradation during staling. Dry crumb (4.0 ± 0.1 mg) in excess water was scanned at 10°C/min, from 5°C to 130°C. The endothermic peak area was converted to enthalpy, the energy required to melt the crystalline material. Enthalpy values were used as an index of starch recrystallization that occurred during storage (Zeleznaek and Hosenev 1987). Each sample was scanned in triplicate.

Statistical Analyses

All experiments were performed in triplicate. The general linear model procedure of SAS (ver. 6.10, SAS Institute, Cary, NC) was used for analysis of quality data. Fisher's LSD test was used to compare means at the 5% significance level. Pearson correlation coefficient was calculated using Statistica for Windows Release 4.5 (StatSoft, Inc., Tulsa, OK).

RESULTS AND DISCUSSION

Physicochemical Properties of Flours

The control flour Trenton, selected for its high gluten strength, had the highest protein content and mixing properties among the three genotypes (Table I). The two waxy durum flours displayed fairly high protein content (15.1–16.0% compared with 17.0% in

Trenton) but possessed very weak dough mixing properties as indicated by low mixing time (4.5–4.8 min compared with 25.8 min in Trenton), and low mixing stability (3.0–3.3 min compared with 29.8 min in Trenton). The waxy durum genotypes displayed much higher starch damage than Trenton, which may be attributed to the higher kernel hardness of the durum samples, and also due to lower resistance of waxy starch granules to mechanical damage than normal starch (Bettge et al 2000). The amylose content of the waxy durum flour samples was 3.5–3.6% compared with 26.6% in Trenton, while the α -amylase activity of the flours was 0.05–0.09 CU/g.

The RVA pasting profiles of the genotypes were evaluated in 1 mM AgNO₃ instead of water to suppress any possible amylase activity that could mask the actual pasting behavior of the flour samples. The waxy genotypes took less time to reach peak viscosity than the control sample (3 min compared with 6 min) (data not shown). They displayed pasting profiles typical of a low-amylose starch, with very high peak viscosity, high breakdown, and low setback compared with Trenton (Table II). Waxy2 had the highest peak viscosity, followed by Waxy1, whereas Trenton had a much lower peak viscosity. However, when 10, 20, and 30% waxy flour was added to Trenton, it did not significantly change the peak viscosity of the blend. Trenton displayed high HPV and CPV values which decreased very gradually as the ratio of waxy flour increased in the blends. In contrast, the waxy flours at 100% had much lower HPV and CPV than the blends. Similarly, the breakdown and setback values of the blends were comparable with Trenton but markedly different from that of 100% waxy flours. We hypothesize that the high strength protein of the control flour interacted with the waxy starch granules in the blends, thereby imparting strength to the granules and protecting them from complete rupture and disintegration. In the absence of control flour however, the starch granules of 100% waxy wheat were comparatively more fragile when subjected to heat and shear forces and had higher breakdown and lower setback values. Moreover, the highly branched amylopectin molecules of waxy genotypes may imbibe excess water causing the starch granules to swell to a greater extent than normal starches with subsequent rupture and complete breakdown of the granules to weaken gel structure.

As expected, the 100% waxy flours did not form a firm gel and demonstrated very low hardness and adhesiveness values (Table II). Firmness ranged from 2.6 g in Waxy1 to 3.5 g in Waxy2, whereas that of Trenton was 45.2 g. Adhesiveness ranged from –7.17 g/sec in waxy flours to –33.81 g/sec in Trenton, indicating that the gel formed with 100% waxy flour was extremely soft and weak. Quite interestingly, as the level of waxy flour increased in the blends, the gels turned softer compared with 100% Trenton, as shown by lower textural parameters. This implies that while waxy flour in the blending ratio of 10–30% has very little influence on the pasting parameters of normal flour, it has a distinct impact on the final setting of the flour gel, thus providing indirect evidence of its role in retarding staling in flour-based end products.

Influence of Blending Waxy Flour with Bread Flour on Breadmaking Quality

To study the effect of waxy durum flour on bread quality and staling, it was first necessary to establish an optimum proportion of blend that would result in an acceptable quality loaf. The base flour Trenton was blended with 10, 20, and 30% waxy flour, mixed into optimum doughs, and baked into 100-g loaves using a straight-dough method. The blends showed a slight but significant decrease in loaf volume compared with Trenton, but the variation in volume between the different ratios was not significant (Table III). The crumb grain and texture at 10% and 20% were fairly comparable with Trenton but 30% waxy flour resulted in rather large and open crumb grain structure with lower scores. As expected, the crumb whiteness was notably reduced as the ratio of durum flour increased in the blend, although the yellowish tinge from the durum flour was not discernible at ratios <30%. Based on the overall appearance of the loaves, a ratio of 10–20% waxy flour was comparable with the control in terms of loaf quality.

Influence of Waxy Flour Blends on Bread Staling Properties

The loaves were tested for firmness, enthalpy, and moisture loss on day 0, 3, and 5 after baking to evaluate whether the addition of waxy flour had any effect on the above parameters. The firmness

TABLE I
Physicochemical Properties of Control and Waxy Durum Wheat Flours

Genotypes	Protein (%)	Amylase (CU/g)	Amylose (%)	Starch Damage (%)	Farinograph		
					Absorption (%)	Mixing Time (min)	Mixing Stability (min)
Trenton	17.0a ^a	0.09a	26.6a	6.5c	66.8b	25.8a	29.8a
Waxy1	16.0b	0.05b	3.5b	12.9b	77.7a	4.5b	3.3b
Waxy2	15.1c	0.06b	3.6b	13.8a	77.0a	4.8b	3.0b

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE II
Pasting Parameters and Textural Properties of Waxy and Bread Flour Blends

Genotypes	Pasting Characteristics ^a					Texture Profile ^b	
	PV	HPV	CPV	BKD	STB	HA	AD
100% Trenton	152	110	197	42	87	45	–33.8
Waxy1							
10%	152	102	187	50	85	35	–23.7
20%	148	100	181	48	81	24	–21.2
30%	149	102	179	48	78	20	–16.5
100%	274	97	126	177	29	3	–7.2
Waxy2							
10%	150	101	186	49	85	32	–24.5
20%	147	98	183	49	85	22	–16.8
30%	149	98	178	50	80	20	–15.5
100%	270	94	124	176	30	4	–7.2
LSD ^c	5.5	5.2	4.6	5.2	4.2	2	2.6

^a PV = peak viscosity (RVU), HPV = hot paste viscosity (RVU), CPV = cold paste viscosity (RVU), BKD = breakdown, STB = setback.

^b HA = hardness (g), AD = adhesiveness (g/sec).

^c Least significant difference ($P < 0.05$).

of the bread crumb remained similar for all the treatments on day 0 (Table IV). As storage time increased to day 3, there was a sharp increase in firmness of all the loaves, with Trenton showing the highest firmness values followed by the 10% blend, whereas loaves made with 20 and 30% blends remained significantly softer. On day 5, Trenton and the 10% blend showed a further increase in firmness, whereas the 20 and 30% blends gave comparatively lower values. The large increase in firmness from day 0 to day 3 was mostly attributed to moisture migration from crumb to crust that is usually associated with staling (Pylar 1988). Quite interestingly, the total moisture content in the crumb measured over time was statistically similar for all the loaves (data not shown), indicating that the delayed firming observed with waxy blends was not moisture related. Based on the above results it was concluded that increase in bread firmness with time was inevitable but addition of waxy flour at 20–30% slowed the firming process considerably.

Enthalpy of the crumb, which is a measure of starch retrogradation, was not significantly different between treatments on day 0 (Table IV), irrespective of the amount of waxy flour in the blend. However, by day 3 there was a substantial increase in enthalpy among all the treatments, followed by a much more gradual but significant increase on day 5. Among treatments, the control loaf had the highest enthalpy on day 3 and 5, which decreased significantly as the ratio of waxy blends increased. The enthalpy values were in accordance with the firmness results, and showed a retarded rate of staling in 20–30% waxy flour. Hayakawa et al (1997) also observed that the increase in enthalpy over time was much lower in waxy samples than in control counterparts, and they concluded that waxy wheat starch is resistant to retrogradation.

The results indicated that a blend containing 10% waxy flour was too low to influence bread firmness but 20 and 30% waxy blends

impeded staling. However, blends with 30% waxy flour produced loaves with undesirable loaf color and texture. Hence, they were not used for further testing. A blend containing 20% waxy flour was optimal in retarding staling without having a detrimental effect on crumb quality and color, and this blending ratio was used to compare the texture conferred by waxy flour with that obtained by shortening.

Influence of Waxy Flour Blend vs. Shortening on Bread Quality and Staling

The loaf volumes were higher with shortening, irrespective of the amount of waxy flour (Table V), whereas the crumb color and texture were not significantly different for all the treatments (data not shown). The firmness of the loaves at different treatments was not significantly different on day 0. On day 5, bread firmness of Trenton was highest in the absence of shortening (200 g), whereas addition of shortening decreased firmness substantially (181 g). When 20% waxy flour was added to Trenton, either alone or with additional shortening, the loaves displayed a further decrease in the firmness values. DSC results were in agreement with firmness data. Enthalpy values were statistically similar for all treatments on day 0. On day 5, loaves with 20% waxy flour blend displayed significantly lower enthalpy values than the control (2.69 vs. 3.07 J/g). Addition of shortening to the waxy flour further decreased the enthalpy values. Thus, the data suggests that waxy flour has some influence on retarding bread staling, which is in agreement with the findings of other researchers. Ghiasi et al (1984) found that addition of waxy barley flour to high protein wheat flour resulted in low firmness values on storage. Biliaderis (1992) stated that starch retrogradation was a biphasic phenomenon consisting of early complexing of amylose followed by a slow and gradual recrystallization of amylopectin. Therefore, reducing the amylose content would eliminate the rapid early component of staling. Hug-Iten et al (1999) compared the microstructure of starch in fresh and aged bread crumb using light microscopy. Fresh bread crumb showed gelatinized starch granules accompanied by the loss of birefringence. The amylose was phase-separated from the amylopectin and was concentrated in the center of starch granules. On aging, the bread crumb regained birefringence, which was most intense in the amylose-rich center of starch granules, followed by slight birefringence in the amylopectin-rich outer zones. They hypothesized that the reorganization of the intragranular amylose fraction enhances the rigidity of starch granules on bread staling. Our results also suggest that lowering the amylose fraction in bread flour retards staling and extends product shelf life. We speculate that addition of waxy flour dilutes the amylose in the bread flour, thus reducing the amount available for initial staling of fresh bread. With prolonged storage,

TABLE III
Effect of Blending Waxy Durum Flour with Bread Flour on Bread Loaf Volume, Grain and Texture, and Crumb Color

Treatment	Loaf Volume (cm ³)	Grain and Texture ^a	Crumb Color ^a
100% Trenton	1,018a ^b	7.8a	8.6a
Waxy1			
10%	988b	7.5a	7.5b
20%	983b	7.5a	7.3b
30%	980b	6.7b	6.3c

^a Scores of 0–10, with 10 being the best.

^b Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE IV
Effect of Blending Waxy Durum Flour with Bread Flour on the Firmness and Enthalpy of Bread Loaves for Days After Baking

Treatment	Firmness (g)			Enthalpy (J/g)		
	Day 0	Day 3	Day 5	Day 0	Day 3	Day 5
Trenton	35a ^a	138a	192a	0.62a	2.83a	3.12a
Waxy1						
10%	34a	127ab	191a	0.59a	2.70ab	2.94ab
20%	28a	90bc	141bc	0.47a	2.39ab	2.80ab
30%	27a	74c	120c	0.46a	2.37b	2.55b

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE V
Effect of Shortening on Firmness and Enthalpy for Bread Loaves Made with Trenton and 20% Waxy Durum Flour for Days After Baking

Treatment	Loaf Volume (cm ³)	Firmness (g)		Enthalpy (J/g)	
		Day 0	Day 5	Day 0	Day 5
Trenton					
No shortening	1,033b ^a	36.3a	200a	0.72a	3.07a
+ 3% shortening	1,105a	32.5a	181ab	0.69a	2.78ab
+ 20% Waxy2	1,016b	29.6a	152bc	0.65a	2.69b
20%Waxy2 + 3% shortening	1,097a	32.1a	142c	0.63a	2.48b

^a Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

highly branched amylopectin polymers gradual associate to form complexes with a concomitant increase in bread firmness. We also hypothesize that branched amylopectin polymers bind water more effectively, thereby producing softer bread. Though much information can be gained by artificially mixing waxy starch with normal starch, our ultimate aim is to produce hexaploid wheat lines possessing inherent starch characteristics with added quality for baked products, both fresh and frozen. Further work is being conducted to characterize the starches obtained from waxy genotypes and to develop spring hexaploid wheats with partial waxy characteristics that would produce bread with high loaf volume and prolonged shelf life without the need for expensive shortenings and dough conditioners.

CONCLUSIONS

Addition of waxy durum flour to a high protein bread flour at 10, 20, and 30% significantly decreased firming of bread. Waxy blends of 20 and 30% were most effective at reducing the rate of staling as shown by lower firmness and enthalpy values of the loaves. Loaves produced from a 20% waxy durum blend displayed good external and internal texture comparable with the control flour. The enhanced softness of loaves made with a 20% waxy blend was more pronounced than that obtained with 3% shortening, suggesting the possible use of waxy flour as an economical replacement for shortening in the baking industry.

ACKNOWLEDGMENTS

We gratefully acknowledge the technical assistance of Lois Berglund and Angela Ostenson.

LITERATURE CITED

American Association of Cereal Chemists. 2000. Approved Methods of the AACC, 10th ed. Methods 10-09, 44-15A, 46-30, 54-21, 74-09. The Association: St. Paul, MN.

Armero, E., and Collar, C. 1998. Crumb firming kinetics of wheat breads with anti-staling additives. *J. Cereal Sci.* 28:165-174.

Bettge, A. D., Giroux, M. J., and Morris, C. F. 2000. Susceptibility of waxy starch granules to mechanical damage. *Cereal Chem.* 77:750-753.

Bhattacharya, M., and Corke, H. 1996. Selection of desirable starch pasting properties in wheat for use in white salted or yellow alkaline noodles. *Cereal Chem.* 73:721-728.

Bhattacharya, M., Jafari-Shabestari, J., Qualset, C. O., and Corke, H. 1997. Diversity of starch pasting properties in Iranian hexaploid wheat landraces. *Cereal Chem.* 74:417-423.

Biliaderis, C. G. 1992. Structures and phase transitions of starch in food systems. *Food Technol.* 46:98-109.

Boyacıoğlu, M. H., and D'Appolonia, B. L. 1994. Characterization and utilization of durum wheat for breadmaking. I. Staling properties of bread baked from bread wheat flours and durum wheat flours. *Cereal Chem.* 71:34-41.

Callejo, M. J., Gil, M. J., Rodriguez, G., and Ruiz, M. V. 1999. Effect of gluten addition and storage time on white pan bread quality: Instrument evaluation. *Food Res. Technol.* 208:27-32.

Champenois, Y., Valle, G., Planchot, V., Buleon, A., and Colonna, P. 1999. Influence of alpha-amylases on bread staling and on retrogradation of wheat starch models. *Sci. Aliment.* 19:471-486.

Collar, C., Armero, E., and Martinez, J. 1998. Lipid binding of formula bread doughs. *Food Res. Technol.* 207:110-121.

De Stefanis, V. A., Ponte, J. G., Jr., Chung, F. H., and Ruzza, N. A. 1977. Binding of crumb softeners and dough strengtheners during breadmaking. *Cereal Chem.* 54:13-24.

Defloor, I., and Delcour, J. A. 1999. Effect of maltodextrins and antistaling enzymes on the differential scanning calorimetry staling endotherm of baked doughs. *J. Agric. Food Chem.* 47:737-741.

Faheid, S. M. M., and Ragab, G. H. 1996. Effect of added surfactants on rheological, organoleptic properties and staling rate of pan bread. *Egyptian J. Food Sci.* 24:311-330.

Forsell, P., Shamekh, S., Harkonen, H., and Poutanen, K. 1998. Effects of native and enzymatically hydrolysed soya and oat lecithins in starch

phase transitions and bread staling. *J. Sci. Food Agric.* 76:31-38.

Genc, M., Aslan, A., and Olcay, M. 2000. The production of the derivatives of monoglycerides in breadmaking and investigation of its potential uses. *Adv. Food Sci.* 22:81-85.

Gerrard, J. A., Every, D., Sutton, K. H., and Gilpin, M. J. 1997. The role of maltodextrins in the staling of bread. *J. Cereal Sci.* 26:201-209.

Ghiasi, K., Hosney, R. C., Zeleznak, K., and Rogers, D. E. 1984. Effect of waxy barley starch and reheating on firmness of bread crumb. *Cereal Chem.* 61:281-285.

Graybosch, R. A. 1998. Waxy wheats: Origin, properties, and prospects. *Trends Food Sci. Technol.* 9:135-142.

Hayakawa, K., Tanaka, K., Nakamura, T., Endo, S., and Hoshino, T. 1997. Quality characteristics of waxy hexaploid wheat (*Triticum aestivum* L.): Properties of starch gelatinization and retrogradation. *Cereal Chem.* 74:576-580.

Hosney, R. C. 1994. Yeast leavened products. Pages 250-263 in: Principles of Cereal Science and Technology. Am. Assoc. Cereal Chem.: St. Paul, MN.

Hug-Iten, S., Handschin, S., Conde-Petit, B., and Escher, F. 1999. Changes in starch microstructure on baking and staling of wheat bread. *Food Sci. Technol.* 32:255-260.

Hugo, L. F., Rooney, L. W., and Taylor, J. R. N. 2000. Malted sorghum as a functional ingredient in composite bread. *Cereal Chem.* 77:428-432.

Inagaki, T., and Seib, P. A. 1992. Firming of bread crumb with cross-linked waxy barley starch substituted for wheat starch. *Cereal Chem.* 69:321-325.

Kim, S. K., and D'Appolonia, B. L. 1977. Bread staling studies. I. Effect of protein content on staling rate and bread crumb pasting properties. *Cereal Chem.* 54:207-215.

Kiribuchi-Otobe, C., Yanagisawa, T., Yamaguchi, I., and Yoshida, H. 1998. Wheat mutant with waxy starch showing stable hot paste viscosity. *Cereal Chem.* 75:671-672.

Krog, N., Olesen, S. K., Toernaes, H., and Joensson, T. 1989. Retrogradation of the starch fraction in wheat bread. *Cereal Foods World* 34:281-285.

Lee, Y. T., Schwarz, P. B., and D'Appolonia, B. L. 1998. Functional properties of beta-glucans from hull-less barley on wheat starch and flour. *Food Sci. Biotechnol.* 7:51-55.

Maleki, M., Hosney, R. C., and Mattern, P. J. 1980. Effects of loaf volume, moisture content, and protein quality on the softness and staling rate of bread. *Cereal Chem.* 57:138-140.

Michniewicz, J., Biliaderis, C. G., and Bushuk, W. 1992. Effect of added pentosans on some properties of wheat bread. *Food Chem.* 43:251-257.

Morgan, K. R., Gerrard, J., Every, D., Ross, M., and Gilpin, M. 1997. Staling in starch breads: The effect of antistaling α -amylase. *Starch* 49:54-59.

Morita, N., Fujita, S., Domon, E., Ando, H., and Mitsunaga, T. 1998. Effect of substitution of waxy-barley flour on the viscoelastic properties of wheat dough and bread making. *J. Appl. Glycosci.* 45:385-391.

Piazza, L., and Masi, P. 1995. Moisture redistribution throughout the bread loaf during staling and its effect on mechanical properties. *Cereal Chem.* 72:320-325.

Pyler, E. J. 1988. Keeping properties of bread. Pages 815-849 in: Baking Science and Technology, 3rd ed. Vol. II. Sosland: Merriam, KS.

Rao, P. A., Nussinovitch, A., and Chinachoti, P. 1992. Effects of selected surfactants on amylopectin recrystallization and on recoverability of bread crumb during storage. *Cereal Chem.* 69:613-618.

Rogers, D. E., Zeleznak, K. J., Lai, C. S., and Hosney, R. C. 1988. Effect of native lipids, shortening, and bread moisture on bread firming. *Cereal Chem.* 65:398-401.

Stauffer, C. E. 2000. Emulsifiers as antistaling agents. *Cereal Foods World* 45:106-110.

Thomas, D. J., and Atwell, W. A. 1997. Starch structure. Pages 1-11 in: Starches. Eagan Press: St. Paul, MN.

Toufeilli, I., Habbal, Y., Shadarevian, S., and Olabi, A. 1999. Substitution of wheat starch with non-wheat starches and cross-linked waxy barley starch affects sensory properties and staling of Arabic bread. *J. Sci. Food Agric.* 79:1855-1860.

Yasui, T., Sasaki, T., and Matsuki, J. 1999. Milling and flour pasting properties of waxy endosperm mutant lines of bread wheat (*Triticum aestivum* L.). *J. Sci. Food Agric.* 79:687-692.

Zeleznak, K. J., and Hosney, R. C. 1987. Characterization of starch from bread aged at different temperatures. *Starch* 39:231-233.

Zhang, D., Moore, W. R., and Doehlert, D. C. 1998. Effects of oat grain hydrothermal treatments on wheat-oat flour dough properties and breadbaking quality. *Cereal Chem.* 75:602-605.

[Received June 12, 2001. Accepted August 24, 2001.]