Heating Conditions and Bread-Making Potential of Substandard Flour

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ABSTRACT: Heating weak bread flours (commercial cookie flour; commercial stone-milled bread flour; Fundulea, a weak bread cultivar) at 80 °C for 15 min had a positive effect on bread volume ($P < 0.05$). This positive effect was best seen when ascorbic acid was removed from bread formulation. Crumb springiness and fineness of grain, but not crumb hardness, were significantly improved after flour heating; cohesiveness improved with heated cookie flour ($P < 0.05$). After heating, flour α-amylase content was lower; dough-mixing stability of cookie flour doubled to 7.1 min but dropped from 18.0 to 4.8 min with standard bread flour. Heating offers possibility to upgrade substandard flour for bread-making applications, especially in oxidant-free dough system.

Key words: flour, heating, bread volume, bread texture, dough rheology

Introduction

HEATING WHEAT FLOUR HAS BEEN PROPOSED TO IMPROVE bread quality (Kent-Jones 1928; Geddes 1929, 1930; Chigurupati and Pulverenti 1994; Wolt and others 1995). However, negative or non-significant results have been reported on loaf volume after heating grain (Hook 1980; Lupano and Añon 1987; Zamponi and others 1990; Kieffer and others 1993), flour (Chigurupati and Pulverenti 1994; Wolt and others 1995), or isolated gluten (Schofield and others 1983; Weegels and others 1994a). Heating grain at about 50 to 70 °C is generally considered deleterious to its germinative and baking qualities, especially at high moisture content (20% and over; Finney and others 1962; Kieffer and Belitz 1993). Industrial production of vital wheat gluten has prompted studies on the effect of drying conditions on its functionality. For example, as for grain, gluten was damaged when it contained more than 20% (Weegels and others 1994b) or 35% moisture (Pence and others 1953).

Control of flour heat treatment is difficult and critical, and this might partly explain variations observed in the literature. For example, after heating isolated gluten around 80 °C for 1 h and incorporating it in bread formulation, loaf volume slightly increased. A major decline was observed, however, over 90 °C (Hay and Every 1990). After heating gluten at 80 °C for up to 24 h, bread volume was equivalent to standard (Veraverbeke and others 1996). With bread flour, short but intense heat treatments (often close to 100 °C) reduced flour moisture to less than 7%, but only slight improvements in loaf volume have been reported (Chigurupati and Pulverenti 1994; Wolt and others 1995). To replace cake flour chlorination, flour treatments over 100 °C have also been proposed (Doe and Russo 1968; Russo and Doe 1970; Gusek and others 1995) but these temperatures would be negative for bread-making applications.

Several studies have been published on the effect of heat on specific gluten proteins (Booth and others 1980; Schofield and others 1983; Weegels and others 1994 a,b). Glutenin has been reported to be the most heat-susceptible fraction above 60 °C. New disulfide bonds are formed leading to increased molecular weight of glutenin aggregates, decreased solubility of proteins, and lowered bread-baking performance. Schofield and others (1983) showed that disulfide/sulfydryl interchange reactions are favored by unfolding of the protein structure. Depending on experimental conditions, gliadin would also be involved in similar types of reactions, generally at a higher temperature than glutenin (Booth and others 1980; Schofield and others 1983; Guerrieri and others 1996). Gluten proteins are more heat-resistant as a flour component than as an extract (Guerrieri and Cerletti 1996).

Incorporation of heat-treated flour or gluten in bread formulation reduces dough extensibility but increases its resistance, viscosity, and stiffness (Kieffer and Belitz 1993; Weegels and others 1994a). To some extent, these effects would mimic the action of oxidizing agents in bread making. For example, ascorbic acid and azodicarbonamide oxidize protein sulfydryl groups to form disulfide bonds. This results in increased dough elasticity and resistance, with positive effects on oven spring and loaf volume (Pyler 1988). The effects of heat treatment on the rheological properties of gluten and dough would vary according to wheat cultivar (Kiefer and Belitz 1993).

Several studies on flour heating have been performed with standard bread flours, often in dough formulations containing chemical oxidants. Under these conditions, it was hypothesized that positive effects of heating are difficult to determine compared to oxidant-free dough system containing weaker bread flour. The aim of this work was to study the effect of heating weak or substandard wheat bread flour to improve its bread-making quality, with or without oxidant in dough formulation.

Materials and Methods

Flour samples

The following flours were used: standard bread flour (11.6% protein; Canada western red spring wheat; unbleached and untreated; Robin Hood Multifoods Inc., Montreal, Quebec, Can.), cookie flour (9.3% protein; Canada soft white spring wheat; non-chlorinated; Tulip; Robin Hood Multifoods Inc.), Fundulea (11.0% protein; weak bread cultivar from Canada red winter wheat provided by J. Frégeau-Reid from ECORC, Agriculture and Agri-Food Canada, Ottawa, Ontario, Can.), and Brio (13.8% protein; stone-milled organic bread flour from Canada western red spring wheat; Minoterie Les Brumes, Batiscan, Quebec, Can.). Portions of 1 kg flour were put into plastic bags and stored at −20 °C until use.

Flour heating

Three hundred and fifty grams of flour were placed in a 1000-mL round bottom flask, except for starch damage and α-amylase assays where 100 g of flour were placed in a 500-mL round bottom flask. Flask was heated by rotation in a water bath (Rotavapor R110; Büchi; Brinkmann Instruments, Rexdale, Ontario, Can.), and temperature was controlled by adjusting water bath temperature. The temperature of the flour was checked with a thermocouple introduced in the opening of the flask.

Flour analyses

Before and after heating, flour moisture was determined according to AACC Method 44-15A (AACC 1995). α-Amylase activity was determined according to ICC rapid method no. 303 (ICC 1998), and results were expressed as Ceralpha Unit (CU) per gram of flour (dry weight). Starch damage was measured according to ICC standard no. 164 (ICC 1998). Flour protein content was obtained with the LECO Nitrogen/Protein Determinator FP-428 (LECO Instruments Ltd, Mississauga, Ontario, Can.); 0.2 g of flour was used. EDTA was the calibration standard, and the conversion factor was 5.7.

Dough rheology

Farinograms were performed twice on duplicate samples according to AACC Method 54-21 (AACC 1995) with the 300-g bowl according to the constant flour weight procedure.

Baking

Dough was prepared with flour (200 g), compressed yeast (7 g), sucrose (6 g), vegetable shortening (6 g), and salt (4 g). In some formulations, 100 mg/kg flour of ascorbic acid was incorporated. Dough water absorption was 106 g (cookie), 116 g (Fundulea), or 124 g (standard bread flour and Brio). With heat-treated flours, water was compensated at the dough stage. Dry ingredients were mixed for 15 sec in a 100- to 200-g mixer (National Mfg. Co., Lincoln, Neb., U.S.A.). Then water (4 °C) was added, and dough was mixed to optimum development. Depending on mixing time, various proportions of ice were added into water to keep dough temperature at 22 to 24 °C after mixing. Dough was bench-rested for 30 min at room temperature under a wet cloth, then sheeted-molded with a sheeter-molder (L & M Co., Downsview, Ontario, Can.). Dough pieces (330 g) were put into pans, proofed at 37 °C and 85% relative humidity to constant height (2.5 cm above rim) and baked at 210 °C for 20 min in a revolving oven (Equipement de Boulangerie L. P., Victoriaville, Quebec, Can.) except for assays on the determination of flour heating conditions (177 °C for 20 min in a convection oven; S. A. Baker's Pride Inc., Lachine, Quebec, Can.). After cooling for 1 h, loaf volume was measured by rapeseed displacement (National Mfg. Co.).

Texture analyses

Crumb elasticity, hardness, gumminess, chewiness, and cohesiveness were measured by the TA-XT2 (Texture Technologies Corp., Scarsdale, N.Y., U.S.A.). The center portion of a bread slice was cut into a circle of 4.5 cm dia with a sharp punch. A TA-25 probe (4.4 cm o.d. aluminum cylinder) compressed crumb sample by 50% of its original height at 1.7 mm/sec with a 3 sec-wait between strokes. Texture data were obtained from 15 replicates (3 doughs × 5 bread slices).

Image analysis of bread crumb

For each condition tested, fineness of grain (number of crumb cells) was determined in triplicate (3 slices) by image analysis. Grayscale images of bread slices were first acquired by a scanner at a resolution of 300 ppi (Scanjett II cx, Hewlett Packard, Singapore). For each greyscale image, a square area of 700 × 700 pixels was selected and transformed in a binary image by assigning black pixels to cells and white ones to the matrix. Isolated pixels, corresponding to noise, were eliminated by application of dilution/erosion filters (Image Processing Tool Kit 2.5 Plug-In/Reinder Games Inc., Photoshop 4.0, Adobe Systems Inc., San Jose, Calif., U.S.A.). Color overlays were applied to the resulting clean binary image. Number of cells was calculated with SigmaScan Pro 5.0 (Jandel Scientific Inc., Chicago, Ill., U.S.A.).

Statistical methods

Effect of flour heating conditions. A 3-×-4 (time and temperature) factorial design plus a control was used. The experiment was repeated 4 times. Because the control level was not crossed with any of the levels of the factors, the 2 factors and the control were combined into a global factor with 13 levels. Analysis of variance was performed at the 5% significance level using the general linear models procedure (SAS Institute Inc. 1989). Differences among treatment levels were determined with 95% confidence intervals.

Effect of ascorbic acid. A 3-×-3-×-2 (flour, heat treatment, and ascorbic acid) factorial design in a split-split-plot layout was used. The ascorbic acid treatment was applied to subsub batches of flours that were allocated one of the 3 levels of the heat treatment. The experiment was repeated 4 times. Analysis of variance was performed at the 5% significance level using the general linear models procedure (SAS

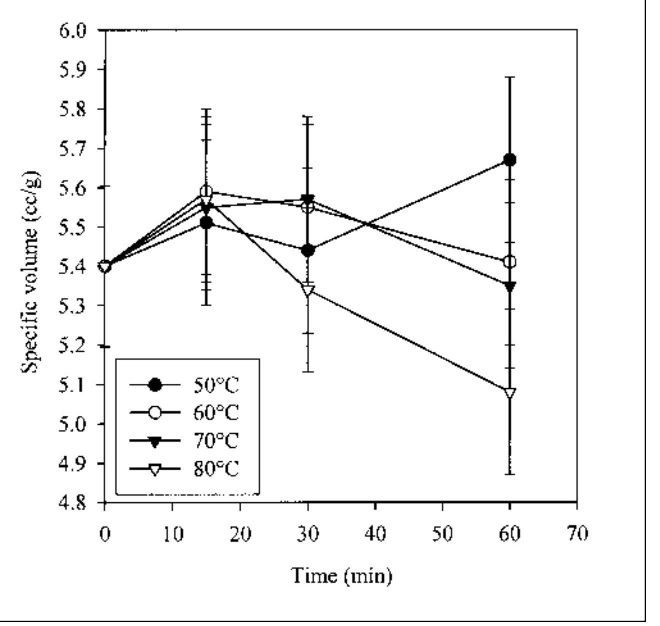

Figure 1—Effect of flour heating conditions on specific volume of bread made with standard bread flour. Control was baked from non-heated flour. Formulations contained 100 mg/kg flour of ascorbic acid. Data are means of 4 determinations with 95% confidence intervals. When confidence intervals overlap, means are not significantly different.

Table 1—Effect of heat treatment (80 °C; 20 min) on farinogram characteristics of flours[a]

Flour	Heat treatment	Absorption[b] (%)	Arrival time (min)	Peak time (min)	Stability (min)
Standard	No	63.16	1.50	2.50	18.00
	Yes	62.60	1.25	2.00	4.75
Cookie	No	54.29	1.00	2.00	3.63
	Yes	53.09	0.63	1.50	7.08
(Standard error)		0.05	0.06	0.00	0.27

[a]Farinograms were performed in duplicate.
[b]Based on 14% moisture.

Table 2—Effect of flour heat treatment (80 °C; 15 min) on starch damage and α-amylase content

Flour	Heat treatment	Starch damage[a] (% dry matter)	α-amylase[a] (CU/g dry matter)
Standard	No	8.16	0.078
	Yes	7.50	0.029
Cookie	No	3.81	0.126
	Yes	3.62	0.071
Fundulea	No	4.06	0.139
	Yes	3.86	0.090
Brio	No	6.54	0.161
	Yes	6.21	0.105
(Standard error)		0.09	0.004

[a]Data are means of 3 repetitions, each made in duplicate.

Institute Inc. 1989). Differences among treatment levels were determined with 95% confidence intervals.

Effect of heating on flour, dough, and bread characteristics. A 4-×-2 (flour type and heat treatment) factorial design in a split-plot layout was used. Batches of flour were subdivided according to heat treatment or not (control). The experiment was repeated 3 times. Analysis of variance was performed at the 5% significance level using the general linear models procedure (SAS Institute Inc. 1989). For cohesiveness, the analysis of variance showed a significant flour x heating interaction, which indicated that the effect of the treatment depended on the flour type. Hence, multiple comparisons were used to determine the effect of the treatment on each flour type. In order to keep the risk of committing type I errors (declaring differences that do not exist), the Bonferroni correction was applied. It consists of dividing the alpha level by the number of means to compare, in this case $\alpha' = \alpha/4 = 0.05/4$. When difference between means was lower than the corrected level, means were declared significantly different.

Results

Effect of flour heating conditions

Figure 1 presents specific volumes of bread made from standard bread flour previously heated at various temperatures and times. Ascorbic acid was present in dough formulation, and the range of temperatures was selected in preliminary studies. At 90 °C and over, treatment for 15 min was very negative for dough that lost much of its extensibility and elasticity (data not shown). Heating at 80 °C for more than 15 min was deleterious to bread specific volume, but not at 50 °C when tested up to 60 min. Heat treatments between 50 and 80 °C for 15 min did not have a negative effect on loaf volume, and these conditions were retained for the rest of the study (Figure 1).

Table 3—Analysis of variance on starch damage and α-amylase content of flours

Variable	Source of variation	df	Sum of squares	Mean square	F-value	Probability
Starch damage	Rep	2	0.16	0.08		
	Flour	3	70.42	23.47	1864	<0.0001
	Rep x flour	6	0.08	0.01		
	Heating	1	0.70	0.70	25.57	0.0010
	Flour x heating	3	0.22	0.07	2.62	0.1226
	Error	8	0.22	0.03		
	Total	23	71.79			
α-Amylase	Rep	2	0.00063	0.00031		
	Flour	3	0.02093	0.00698	127.97	<0.0001
	Rep x flour	6	0.00033	0.00005		
	Heating	1	0.01652	0.01652	443.80	<0.0001
	Flour x heating	3	0.00007	0.00002	0.6495	0.6051
	Error	8	0.00030	0.00004		
	Total	23	0.03878			

Effect of ascorbic acid

Because bread formula tested above included ascorbic acid, it was hypothesized that this oxidant might mask some effect of flour heating on bread volume, carrying the oxidation process too far. In addition, the effect of heat treatment was checked with commercial cookie flour characterized by its very weak gluten compared with standard bread flour. Because the effect of ascorbic acid was the same for all flours, data presented in Figure 2 were combined mean specific volumes obtained for 3 flours (standard bread flour, cookie flour, and a 50/50 mix of these flours) heat-treated at 50 °C for 60 min or 80 °C for 15 min. Statistical analysis revealed a significant interaction between the effect of heat treatment and that of ascorbic acid, whatever the flour tested ($P < 0.05$). In Figure 2, the addition of ascorbic acid improved specific volume of bread made from control (non-heated) or flour heat-treated at 50 °C for 60 min. However, this positive effect was not observed at 80 °C for 15 min ($P < 0.05$). These results showed that, without ascorbic acid in dough formulation, heating flour at 80 °C for 15 min was better than 50 °C for 60 min ($P < 0.05$). For these reasons, it was decided to keep a single flour heat treatment (80 °C/15 min) and remove ascorbic acid from dough formulation for the rest of the experiments.

Effect of heating on flour and dough characteristics

Table 1 shows farinogram data for standard bread flour and cookie flour after heat treatment at 80 °C. Compared to control (non-heated), mixing stability increased from 3.63 to 7.08 min for heated cookie flour but dropped from 18.00 to 4.75 min for standard bread flour. For cookie flour only, flour heat treatment slightly reduced dough water absorption ($P < 0.05$). Other farinograph data (arrival time and peak time) dropped after flour heat treatment ($P < 0.05$); statistical analysis did not reveal a significant interaction between the effects of heat treatment and flour, which means that heat treatment had the same effect on arrival time and peak time for all flours.

To determine further the effects of heating on flour characteristics, the following flours with variable protein content and strength were heat-treated at 80 °C for 15 min: a bread flour (standard), a cookie flour, a stone-milled bread flour (Brio), and a weak bread flour (Fundulea). As shown in Table 2 and confirmed by statistical analysis (Table 3), starch damage and α-amylase data of flours were reduced by heat treatment ($P < 0.05$). Statistical analysis did not reveal a significant inter-

Table 4—Effect of flour heat treatment (80 °C; 15 min) on bread specific volume, texture and number of crumb cells[a]

Flour	Heat treatment	Specific volume (cc/g)	Texture			Number of crumb cells[c]
			Hardness (g)	Springiness	Cohesiveness[b]	
Standard	No	5.10	436.7	0.964	0.747[a]	1087
	Yes	5.11	413.2	0.970	0.740[ab]	1138
Cookie	No	4.33	810.6	0.937	0.551[e]	709
	Yes	4.80	697.1	0.943	0.622[d]	965
Fundulea	No	4.99	551.8	0.938	0.633[cd]	869
	Yes	5.31	544.2	0.941	0.649[cd]	1085
Brio	No	4.67	610.1	0.952	0.685[bc]	956
	Yes	4.92	609.0	0.962	0.708[ab]	1153
(Standard error)		0.12	51.2	0.003	0.009	36

[a]Data for specific volume are means of 3 repetitions. Texture data were obtained from 15 values (3 doughs × 5 bread slices). Data for number of crumb cells were obtained from 9 values (3 doughs × 3 bread slices).
[b]Means followed by the same letter are not significantly different ($P < \alpha'$, or 0.05/4).
[c]Number of crumb cells was determined in an area of 700 × 700 pixels selected on the scanned image of a bread slice.

action between the effects of heat treatment and flour (Table 3), which means that heat treatment had the same effect on all flours. While a major drop (about 35% or more) of α-amylase activity was expected after heating, starch damage results probably showed starch resistance to enzyme attack rather than damage itself.

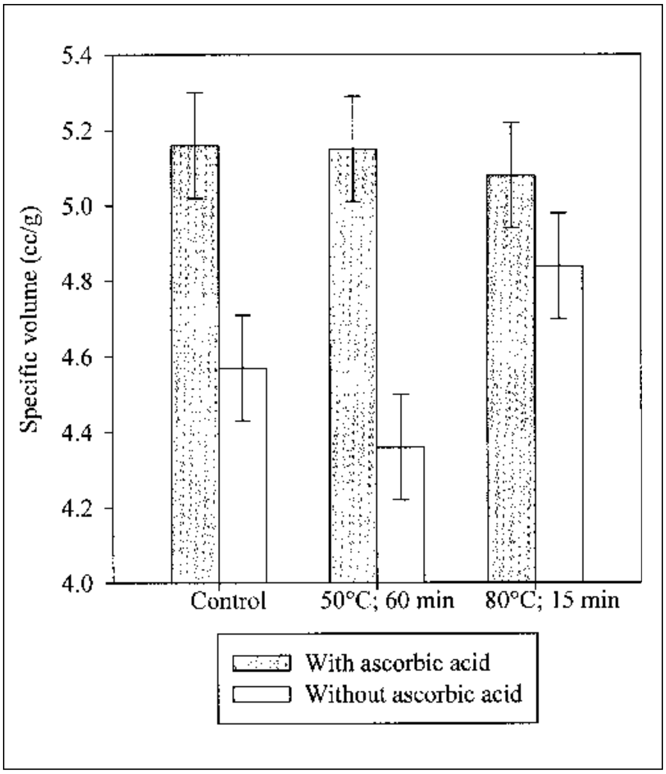

Figure 2—Effect of flour heating conditions and ascorbic acid (100 mg/kg flour) in dough formulation on bread specific volume. Data are means of 4 determinations. The effect being the same whatever the flour; data are means of 3 flour types (standard, cookie, and a 50/50 mix of these flours). Data are means of 4 determinations with 95% confidence intervals. When confidence intervals overlap, means are not significantly different.

Effect of heating on bread characteristic

Without ascorbic acid in dough formulation and for all 4 heat-treated flours (80 °C; 15 min), bread specific volume and crumb springiness but not hardness were improved ($P < 0.05$; Table 4). This was confirmed by analysis of variance (Table 5). For these attributes, statistical analysis did not reveal a significant interaction between the effect of the heat treatment and flour (Table 5), which means that the effect of the heat treatment was the same for all flours. For cohesiveness, there was a significant interaction (Table 5), so means presented in Table 4 could be compared through letters ($P < \alpha'$); only cookie flour was significantly improved after heat treatment. Heating stone-milled flour (Brio) or cookie flour also gave crumb cohesiveness comparable to bread made with standard bread flour. Other texture parameters (gumminess and chewiness) were not significantly different (data not shown).

Table 4 presents data from image analyses of bread samples discussed above. The number of crumb cells within a fixed area increased after heat treatment ($P < 0.05$). Statistical analysis did not reveal a significant interaction between the effect of the heat treatment and flour (Table 5), which means that heat treatment had the same effect for all flours. Without ascorbic acid in formulation, a typical image of a slice of bread prepared without (A) and with (B) heat-treated cookie flour showed that fineness of crumb grain greatly improved with heat-treated flour (Figure 3).

Discussion

Heating under specific conditions improved the quality of flour in bread-making applications, namely in volume, texture, and appearance. These results were evident with flours characterized by weak gluten and in oxidant-free dough system. Control of flour heating conditions is critical and might also explain why flour reacts differently to heat, according to literature. For example, this study has been performed under close temperature control of flour itself rather than air inlet and outlet (Chigurupati and Pulverenti 1994). Heating is also very difficult to control in flour due to the small size of particles that dehydrate very rapidly but tend to form aggregates (Matvoff 1971). For example, heating grain instead of flour might be an alternative to solve these problems.

Heating is generally considered negative for gluten functionality (Kieffer and others 1993; Weegels and others 1994a).

Table 5—Analysis of variance on bread specific volume, texture and number of crumb cells

Variable	Source of variation	df	Sum of squares	Mean square	F-value	Probability
Specific volume	Rep	2	0.3	0.16		
	Flour	3	1.4	0.45	10.77	0.0079
	Rep x flour	6	0.3	0.04		
	Heating	1	0.4	0.42	10.62	0.0116
	Flour x heating	3	0.2	0.06	1.38	0.3171
	Error	8	0.3	0.04		
	Total	23	2.8			
Hardness	Rep	2	23505.4	11752.7		
	Flour	3	336579.3	112193.1	12.38	0.0056
	Rep x flour	6	54386.0	9064.3		
	Heating	1	7957.6	7957.6	1.01	0.3435
	Flour x heating	3	12275.7	4091.9	0.52	0.6796
	Error	8	62808.7	7851.1		
	Total	23	497512.5			
Springiness	Rep	2	0.00006	0.00003		
	Flour	3	0.00322	0.00107	31.94	0.0004
	Rep x flour	6	0.00020	0.00003		
	Heating	1	0.00023	0.00023	9.03	0.0169
	Flour x heating	3	0.00004	0.00001	0.58	0.6436
	Error	8	0.00020	0.00003		
	Total	23	0.00395			
Cohesiveness	Rep	2	0.005	0.0027		
	Flour	3	0.083	0.0278	58.17	0.0001
	Rep x flour	6	0.003	0.0005		
	Heating	1	0.004	0.0040	16.03	0.0039
	Flour x heating	3	0.005	0.0016	6.50	0.0154
	Error	8	0.002	0.0003		
	Total	23	0.102			
Number of crumb cells	Rep	2	16069.7	8034.9		
	Flour	3	256461.3	85487.1	45.13	0.0002
	Rep x flour	6	11366.2	1894.4		
	Heating	1	194940.4	194940.4	49.94	0.0001
	Flour x heating	3	36003.6	12001.2	3.07	0.0906
	Error	8	31226.9	3903.4		
	Total	23	546068.0			

After heating gluten, flour, or grain, dough resistance to extension increased, but its extensibility decreased (Kieffer and others 1993; Weegels and others 1994b). However, variable results have been reported for some dough rheology assays. For example, despite a typical increase of dough resistance to extension, flour heating did not affect farinograph stability, even if bread volume was impaired (Weegels and others 1994b). In contrast, loss of dough mixing stability has been reported under heating conditions where bread volume was reduced (Finney and others 1962) or unchanged (Veraverbeke and others 1996). Higher farinograph stability has been reported after heating pastry (soft wheat) or bread flour (hard red spring or winter wheat), without negative effect on bread volume (Chigurupati and Pulverenti 1994; Wolt and others 1995). These conflicting results might partly be attributed to variable response of wheat varieties to heating (Kieffer and Belitz 1993). Results presented here suggested that with heated substandard bread flour, such as cookie flour, positive changes in protein conformation might explain gluten strengthening, as described by Kieffer and others (1993).

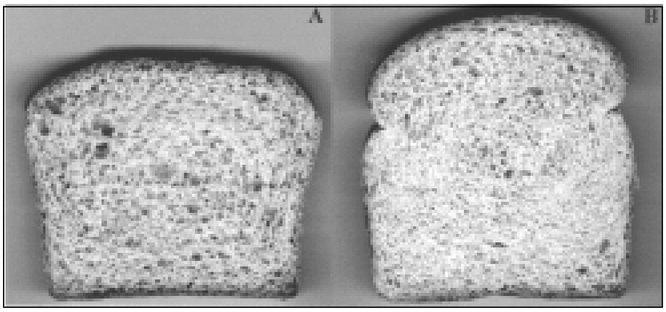

Figure 3—Typical appearance of bread crumb (A) before and (B) after heating cookie flour at 80 °C for 15 min.

Conclusions

IN THIS STUDY, IT WAS HYPOTHESIZED THAT POSITIVE EFFECTS of flour heating were more difficult to determine with standard bread flour with oxidants than with weaker bread flour in oxidant-free dough systems. Without ascorbic acid in dough formulation, results confirmed that heating under specific conditions (80 °C for 15 min) greatly improved the quality of flours with limited bread-making potential. For example, these results apply to substandard bread wheat crops characterized by both high yield and resistance to disease such as cultivar Fundulea. Heating also offers possibilities for making standard- and organic-type breads from additive-free (oxidant) dough systems using whole-wheat flours and alternative cereals, such as spelt, which are steady growing markets for the baking industry.

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