e-Xtra*

Influences of Baking and Thawing Conditions on Quality of Par-Baked French Bread

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ABSTRACT

We examined the effects of baking time and temperature for the preparation of par-baked French bread, and of thawing and second baking conditions on the characteristics of bread prepared from par-baked bread. Par-baked French bread with loaf volume and crumb structure comparable to fully baked bread (control) was obtained with ≥6 min baking at 218°C, which increased the crumb temperature to 97°C. Freezing, thawing, and second baking of par-baked bread decreased loaf volume by ≥100 mL. The second baking time of par-baked bread, which was adjusted to have the bread crumb subjected to 97°C for 14 min based on the crumb temperature profile, produced a darker crust of bread compared with the control. The par-baked bread with 6 min of initial baking at 218°C and frozen at –30°C required 12 min of second baking after thawing for 180 min to ≈20°C to produce crust color, crumb moisture, and firmness comparable to that of the control. When thawing time of par-baked bread was shortened from 180 to 0 min, the second baking time required to yield crust color similar to the control increased from 12 to 16 min. The crumb moisture content was higher in bread baked for 16 min without thawing par-baked bread than those baked after thawing for 45 or 180 min. Lowering the initial baking temperature of par-baked bread from 246 to 163°C with the adjustment of baking time from 4 to 12 min decreased crumb firmness of the re-baked (218°C, 16 min) bread from 2.5 to 1.5 N at 2 hr after baking and from 9.8–10.3 to 6.2–6.3 N at 48 hr.

Cereal Chem. 84(1):38–43

Par-baked bread is partially baked and then baked a second time before being consumed. Freshly baked bread is produced with minimum time and process from par-baked bread because there is no need for dough mixing and proofing or skill. Par-baked bread is generally preferred as a viable labor-saving option in small or in-store bakeries. Unlike frozen dough, which requires the use of specific yeast strains, emulsifiers, and dough strengtheners to retain the quality of bread (Wolt and D'Appolonia 1984a,b; Holmes and Hoseney 1987; Wang and Ponte 1994; Inoue et al 1995; Wang and Ponte 1995), par-baked bread may be produced with little modification of the conventional baking formula.

Influences of dough mixing time, ingredients, and freezing conditions on loaf volume of par-baked bread have been reported by Ferreira et al (1999), Havet et al (2000), Rouillé et al (2000), Carr and Tadini (2003), and Bárcenas and Rosell (2006a). Crumb firmness of par-baked bread has been influenced by the time and conditions of frozen storage and ingredients (Bárcenas et al 2003; Carr and Tadini 2003; Bárcenas and Rosell 2006b). Moisture content of par-baked bread decreases and crumb firmness increases as the frozen storage time of the par-baked bread increases (Bárcenas and Rosell, 2006b). Vulicevic et al (2004) reported that moisture content of crust and crumb, springiness of crumb, and mouthfeel were the most sensitive quality attributes in various types of par-baked bread. Le Bail et al (2005) showed that the chilling condition after partial baking was the most important factor affecting crust flaking of par-baked French bread. Carr et al (2006) reported that par-baked French bread frozen for four days rated superior acceptance compared with a commercial brand in a consumer sensory test. In spite of the popularity of par-baked bread, little information about the baking conditions of par-baked bread is available. We explored the optimum baking time and temperature for making par-baked French bread and determined influences of baking and thawing conditions on quality parameters of bread baked a second time from par-baked bread.

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*The *e*-Xtra logo stands for "electronic extra" and indicates that the online version contains a color version of Fig. 2 not included in the print edition.

DOI: 10.1094/CCHEM-84-1-0038

MATERIALS AND METHODS

Materials

A hard red spring (HRS) wheat flour blend and Rampart, a hard red winter wheat, were obtained from the Western Wheat Quality Lab (Pullman, WA). Rampart was milled using an experimental mill (Buhler, Uzwil, Switzerland). Ash and protein content of HRS wheat flour (0.45 and 16.2% db, respectively) were similar to Rampart (0.45 and 16.3% db, respectively). Mixograph water absorption of Rampart (69%) was higher than that of HRS wheat flour (66%). Mixograph mixing time was 210 sec for both HRS and Rampart.

Analytical Methods

Moisture, protein, and ash contents of wheat flour were determined according to Approved Methods 44-15A, 46-30, and 08-01 (AACC International 2000). Water absorption and mixing time of flours were determined using a 10-g mixograph (National Mfg. Co., Lincoln, NE), according to AACC Approved Method 54-40A.

Characteristics of French Bread

French bread was prepared according to the straight-dough methods described by Baardseth et al (2000) and Tweed (1983). The baking formula consisted of 100 g (14% mb) of flour, 2.0 g of salt, 2.0 g of fresh yeast purchased from a local grocery store, and 0.3 g of barley malt. The constant activity of yeast was monitored throughout the experiments by the baking performance of the control. The dough mixing absorption was determined using a mixograph. All ingredients were mixed in a pin mixer (National Mfg. Co., Lincoln, NE) for 290 sec for HRS and 300 sec for Rampart. The mixing time was optimized based on dough appearance and development during mixing in a 100-g mixer. The dough was covered with a linen cloth, fermented at 24°C and 70% relative humidity for 1 hr, sheeted using a rolling pin to produce dough to 6 mm thick and molded by hand. After the 2 hr proofing to double the volume of the dough, the dough was transferred to a wooden slip, and the surface was cut twice with a razor blade at 5 cm from the both ends. The dough was then transferred onto a ceramic tile in a preheated oven (Whirlpool Co., Benton Harbor, MI) and baked for 20 min at 218°C for the control bread and for the predetermined time at the predetermined temperature. Water (10 mL) was sprayed inside the oven immediately after the transfer of the dough. After baking, the bread was immediately weighed, cooled for 2 hr, measured for volume,

packed in a paper bag, and subjected to further analyses. The loaf volume was measured by rapeseed displacement.

Temperature Profile of Bread Crumb During Baking

French bread was baked from HRS with various baking temperatures of 163, 191, 218, and 246°C for 20 min to observe changes in the temperature of the bread crumb during baking. Two fiber-optic temperature probes (FOT-L/2M) were inserted into the center of the dough before baking. The temperature of the bread crumb was monitored using a UMI 8 multi-channel sequential signal conditioner (FISO Technologies, Inc., Quebec, Canada). The temperature profile was automatically recorded using an FISO Commander V.1.9.0 at 1-min intervals during baking.

Par-baked bread prepared from HRS with 6 min baking at 218°C and stored at –30°C for 7 days was thawed for 0, 45, or 180 min at 22°C. Two fiber-optic temperature probes were inserted into the center of the frozen bread to monitor the temperature of the crumb during thawing. The temperature profile of the crumb during the second baking was monitored as described previously to estimate the optimum second baking time. Time (≈6, 10, or 12 min) required for the crumb of par-baked bread, which was frozen at –30°C and then thawed for 180, 45, or 0 min to reach 97°C during the second baking at 218°C.

Effect of Baking Time on Bread Characteristics

French bread was prepared with baking times of 3, 6, 9, 12, 15, and 20 min at 218°C to determine the influence of baking time on the characteristics of bread. Immediately after baking, the bread was weighed. The bread was then cooled for 2 hr at 22°C and loaf volume, crust color, and crumb moisture content were determined. Crust color was measured with a Minolta camera (CM-2002, Osaka, Japan) with an 11-mm aperture. The color differences were recorded as CIE-LAB values for L^* (lightness), a^* (redness-greenness), and b^* (yellowness-blueness). Moisture content of the bread crumb was determined by oven drying at 105°C for 24 hr.

Effect of Baking Time on Quality of Par-Baked Bread

Par-baked bread was prepared from HRS with baking times of 6, 9, 12, or 15 min, frozen at –30°C for 7 days, thawed for 180 min, and baked a second time for 20, 17, 14, and 11 min, respectively. Because French bread baked once at 218°C for 20 min (control) was subjected to >97°C for 14 min, based on the temperature profile of the bread crumb during baking, the second baking time was calculated to give each bread a total baking time of 14 min at >97°C. Par-baked bread was also prepared with 6 min of baking at 218°C, frozen and thawed for 180 min and baked second time for 12 min to give a crust color comparable to that of the control.

Effect of Thawing Time on Quality of Par-Baked Bread

Par-baked bread was prepared from HRS and Rampart with 6 min of baking at 218°C, frozen at –30°C for 7 days, thawed for 0, 45, or 180 min and baked a second time for 16, 14, and 12 min at 218°C, respectively. The second baking time of par-baked bread was adjusted based on the crust color during baking as compared with the control.

Effect of Initial Baking Temperature on Quality of Par-Baked Bread

Par-baked bread of HRS and Rampart were baked at various baking temperatures of 163, 191, 218, or 246°C with baking times of 12, 10, 6, and 4 min, respectively. The baking time for the specific baking temperature was selected based on the crumb temperature profiles of bread baked at each temperature. The baking time for the preparation of par-baked bread was the time required for the bread crumb to reach 97°C at the specific baking temperature. Par-baked bread was frozen at –30°C for 7 days and baked a second time without thawing for 16 min at 218°C. Characteristics of bread crumb were determined for bread stored for 2 hr and 48 hr at 22°C after baking.

The control and bread baked a second time from par-baked bread were determined for volume, weight, crust color, and crumb moisture content as described previously. Firmness of bread crumb was evaluated with a compression test using a TA-XT2 texture analyzer (Stable Micro Systems, Haslemeres, England). A slice 2.0 cm thick was cut from the center portion of the bread. The slice was placed on a flat metal plate and compressed to 25% of its thickness at a speed of 1.0 mm/sec using a plastic plunger with a flat surface with a 2.5 cm diameter. The peak compression force was collected as firmness of bread crumb.

Bread prepared with various thawing times or various initial baking temperatures were further determined for starch retrogradation of bread crumb. A piece of bread crumb from another center cut of bread was lyophilized and ground to powder using a cyclone mill (Udy Co., Fort Collins, CO) fitted with a perforated screen with 0.25-mm openings for the determination of starch retrogradation. Retrogradation characteristics of starch in the bread crumb were determined using differential scanning calorimetry (DSC, Pyris1, Perkin-Elmer Co., Norwalk, CT). An indium stan-

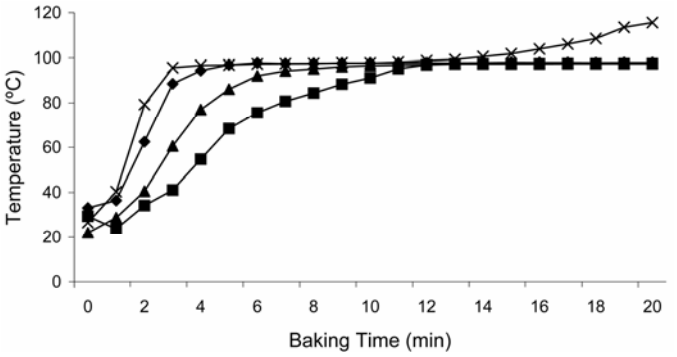

Fig. 1. Crumb temperature of French bread during baking at four different oven temperatures: 163°C (■), 191°C (▲), 218°C (◆), and 246°C (×). Temperature profiles were recorded from the two fiber-optic temperature probes inserted into the center of the dough at 1-min intervals.

TABLE I
Characteristics of French Bread Baked from Hard Red Spring Wheat Flour with Different Baking Times at 218°C[a,b]

	Bread		Crust Color			
Baking Time (min)	Volume (mL)	Weight (g)	L^*	a^*	b^*	Crumb Moisture (%)
3	nd	165a	78.2a	–0.2e	14.6f	47.4a
6	615a	159b	76.7b	–0.4e	17.6e	47.6a
9	648a	151c	70.5c	4.8d	25.9d	47.6a
12	638a	146d	63.1d	12.0c	33.0a	47.4a
15	625a	143e	51.1e	15.4a	29.7b	47.8a
20	615a	137f	48.6f	14.5b	28.2c	47.5a

[a] Values followed by the same letters in the same column are not significantly different at $P < 0.05$.
[b] L^* = lightness; a^* = redness-greenness; b^* = yellowness-blueness; nd = not determined.

dard was used for temperature and enthalpy calibration. Lyophilized bread crumb (10 mg) and distilled water (20 μL) were placed in a stainless steel capsule, sealed, and allowed to equilibrate for 24 hr at 24°C. The samples were then heated in a calorimeter from 20 to 180°C at 10°C/min. A capsule with an inert material (aluminum oxide) and water (1:2 ratio) served as the reference. Onset temperature and peak temperature were determined for each endotherm using Pyris Manager data processing software v. 2.04 (Perkin-Elmer). The transition enthalpy of gelatinization was calculated from the peak area and expressed as J/g of dry matter.

Statistical Analysis

All tests were run at least in duplicate. Least significant difference and analysis of variance were performed using the Statistical Analysis System (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Crumb Temperature Profile of French Bread During Baking

The changes in crumb temperature during baking at various temperatures were monitored to determine the baking time for the preparation of par-baked bread. The crumb temperature reached ≈97°C within 4 min of baking at 246°C, 6 min at 218°C, 10 min at 191°C, and 12 min at 163°C (Fig. 1). With continuous baking, crumb temperature maintained at 98°C with baking temperature <218°C and reached 116°C with 20 min of baking at 246°C. Temperature increase up to 100°C in the crumb and >100°C in the crust of pan bread during baking have been reported by Bloksma (1986). Because bread is a moist product, the crumb temperature cannot exceed 100°C without the product becoming dry (Hoseney 1994). Baking at 246°C for 20 min probably dried the bread crumb and thus increased the crumb temperature to

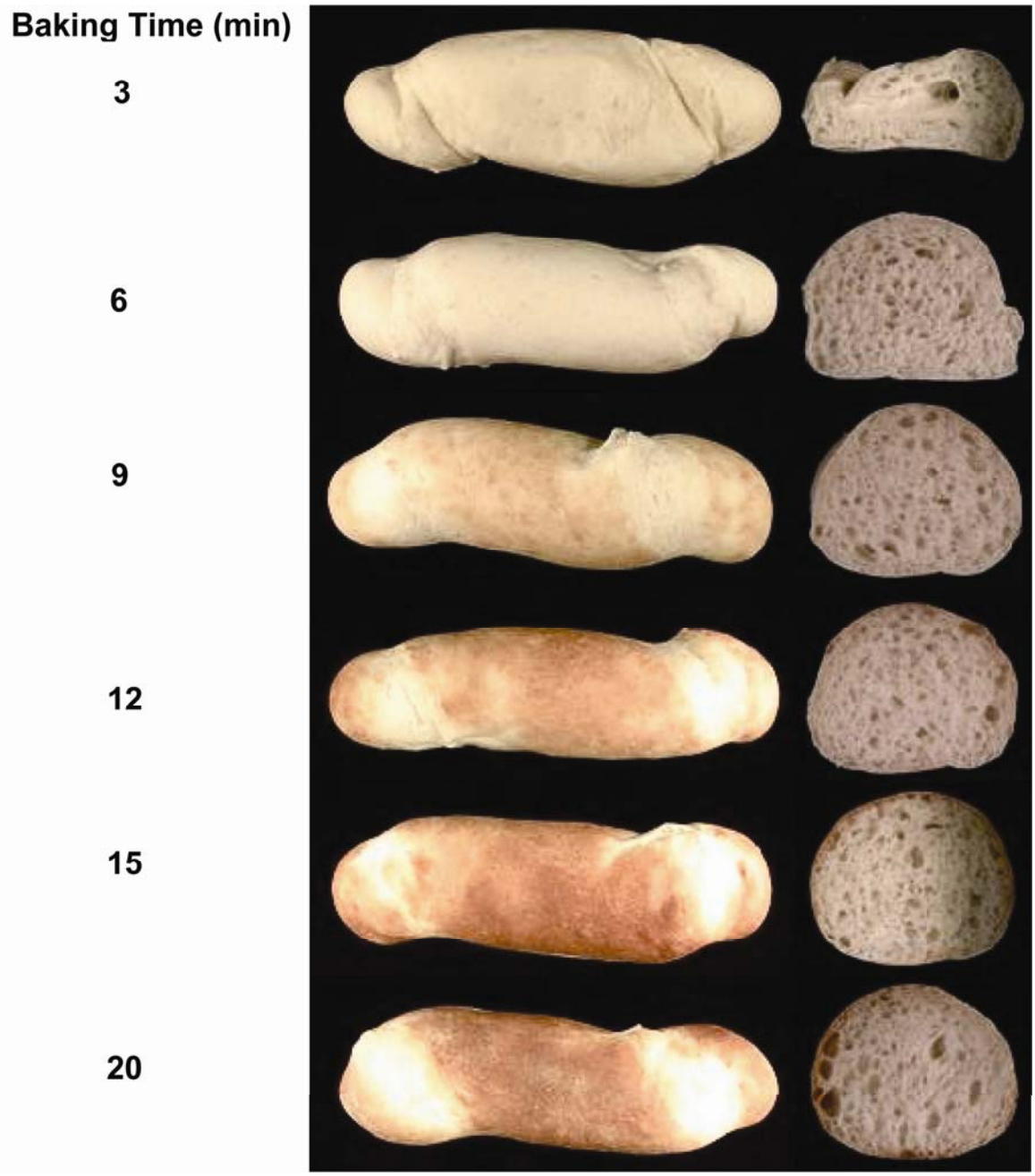

Fig. 2. Appearance and crumb structure of bread baked for different baking times from a hard red spring wheat flour.

>100°C. Accordingly, with a baking temperature of 246°C, bread should be baked for <12 min and the crumb temperature should be <100°C. In bread baked at 218°C for 20 min, bread crumb was subjected to temperatures >97°C for 14 min.

Par-Baked French Bread of Different Baking Times

Three minutes baking at 218°C produced a collapsed bread with an unacceptable crumb structure, while bread baked >6 min retained crumb structure after baking without collapse (Fig. 2). In bread baked for 3 min, incomplete starch gelatinization and protein denaturation probably occurred during baking, subsequently decreasing starch retrogradation for forming a firm crumb structure during cooling, resulting in a collapsed crumb. Crust browning was observed in bread baked for >9 min. Accordingly, it appears that 6 min of baking at 218°C results in starch gelatinization and protein coagulation without the development of the crust color, which is the objective of partial baking in the preparation of par-baked bread (Roussel and Chiron 2002). Bread baked for 6–20 min exhibited similar loaf volume at a range of 615–648 mL. While loaf weight of bread decreased consistently from 165 to 137 g as baking time increased from 3 to 20 min, there were no significant changes in crumb moisture content (Table I). Lack of change in crumb moisture content with extended baking time suggests that moisture loss mainly occurs in the crust area of bread, while there was little loss of moisture in the middle the of bread crumb during baking. As baking time increased from 3 to 20 min, brightness (L^*) of crust decreased and redness (a^*) increased. Yellowness (b^*) of crust increased as baking time increased to 12 min and decreased with further baking.

Temperature Profile of Par-Baked Bread Thawed for Different Times

Par-baked bread prepared with 6 min of initial baking at 218°C was frozen at –30°C for 7 days and baked a second time at 218°C with or without thawing at 22°C. Crumb temperature reached ≈2°C after 45 min and ≈20°C after 180 min of thawing at 22°C. Crumb temperature reached 97°C in 6 min in par-baked bread thawed for 180 min during the second baking, 12 min in bread thawed for 45 min, and 14 min in bread baked without thawing (Fig. 3).

Second Baking Time of Par-Baked Bread

When bread was baked at 218°C for 20 min (control), the bread crumb was maintained >97°C for 14 min (Fig. 1). Because the crumb of par-baked bread reached 97°C in 6 min during the second baking at 218°C with 180 min of thawing (Fig. 3), the par-baked bread prepared with 6 min of initial baking was baked a second time for 20 min to expose the bread crumb to >97°C for 14 min. The second baking times of other par-baked breads with 9–15 min of initial baking were adjusted accordingly. The final bread baked from par-baked bread with 6–15 min initial and 20–11 min of second baking, however, was much darker (lower L^*) and smaller in loaf volume than the control, even though crumb moisture and firmness were comparable to those of the control (Table II). A decrease in loaf volume of bread has also been reported in par-baked French bread (Ferreira et al 1999) and frozen dough bread (Hsu et al 1979; Inoue and Bushuk 1991). Yamauchi et al (1999) observed that freezing promoted the degradation of the crumb structure, which could induce shrinkage of bread, resulting in loaf volume decrease. Shortening the second baking time from 20 to 12 min in par-baked bread with 6 min of initial baking produced bread with crust color, crumb moisture, and firmness similar to those of the control.

Effect of Thawing Time on Par-Baked Bread

Par-baked bread that was baked for 6 min and frozen for 7 days at –30°C was baked a second time with or without thawing. The second baking time for par-baked bread, adjusted based on the crust color, was 16 min for unthawed, 14 min for 45-min thawed, and 12 min for 180-min thawed bread (Table III). Breads baked from par-baked bread were in volume than the control in both wheat flours. Loaf volumes of bread with different thawing times and subsequently different second baking times were similar and had ranges of 480–500 mL in HRS and 480–505 mL in Rampart. Bread baked with different thawing times and the control exhibited similar crust color and crumb firmness, while crumb moisture content increased as the thawing time shortened (Table III). The bread baked from par-baked bread after 180 min of thawing exhibited similar crumb moisture content compared with the control in both wheat flours. Moisture content of the crumb of par-baked bread baked from Rampart was higher than those of HRS wheat flour in the corresponding thawing conditions, probably due to the higher baking water absorption of Rampart (69%) compared with that of HRS (66%). Starch gelatinization enthalpies of the bread crumb were not different among breads of various thawing and baking times and the control with ranges of 0.6–0.7 J/g.

Overall, the thawing time of frozen par-baked bread exhibited no influence on loaf volume, crust, color, crumb firmness, and starch retrogradation of bread baked a second time. Shortening or

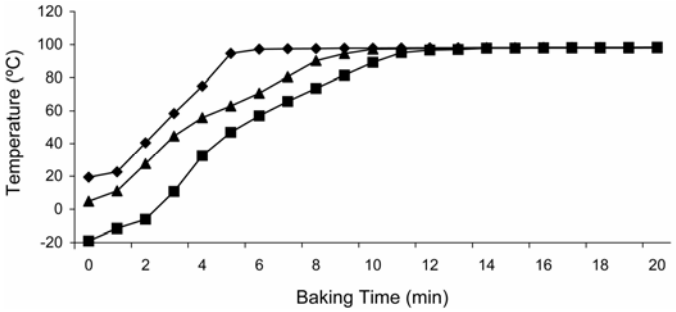

Fig. 3. Temperature profile of par-baked bread crumb during the second baking at 218°C. Bread was baked initially for 6 min at 218°C, frozen at –30°C for 7 days, and thawed for various time periods before the second baking: 0 min (■), 45 min (▲), and 180 min (◆).

TABLE II
Characteristics of French Bread Baked from Par-Baked Bread of a Hard Red Spring Wheat Flour with Different Second Baking Time[a–c]

Baking Time		Bread		Crust Color			Crumb	
1st (min)	2nd (min)	Volume (mL)	Weight (g)	L^*	a^*	b^*	Moisture (%)	Firmness (N)
20	0	615a	137a	48.6a	14.5a	28.2a	47.5ab	2.1a
6	20	490b	131b	40.4b	14.2a	22.4b	47.7a	2.3a
9	17	510b	132b	40.8b	14.2a	21.8b	47.4ab	2.2a
12	14	500b	132b	40.6b	14.6a	22.3b	47.2b	2.2a
15	11	500b	132b	40.9b	14.0a	22.1b	47.3b	2.1a

[a] Values followed by the same letters in the same column are not significantly different at $P < 0.05$.
[b] L^* = lightness; a^* = redness-greenness; b^* = yellowness-blueness.
[c] Baking temperature for both 1st and 2nd baking was 218°C. Par-baked bread was frozen at –30°C for 7 days after the first baking and thawed for 180 min to ≈20°C before the second baking. Second baking time was selected to have bread crumb experience at >97°C for a total of 14 min.

TABLE III
Characteristics of French Bread Baked from Par-Baked Bread with Different Thawing and Second Baking Times[a–d]

Thawing Time (min)	2nd Baking (min)	Bread Volume (mL)	Crust Color			Crumb		
			*L**	*a**	*b**	Moisture (%)	Firmness (N)	Δ*H* (J/g)
Hard Red Spring Wheat								
Control	0	615a	48.6ab	14.5e	28.2abc	47.5c	2.1a	0.6a
0	16	500b	47.7ab	16.9ab	28.9ab	49.7a	2.0a	0.7a
45	14	490b	47.6ab	17.3a	29.5a	48.6b	2.0a	0.7a
180	12	480b	48.6ab	15.8cd	29.6a	48.1c	1.9a	0.7a
Rampart								
Control	0	610a	48.9a	15.0de	27.8bc	48.7c	1.9a	0.6a
0	16	500b	47.5b	15.6cd	27.3c	50.6a	1.9a	0.7a
45	14	505b	47.6ab	16.2bc	29.0ab	49.5b	2.0a	0.7a
180	12	480b	47.5b	15.6cd	27.3c	48.6c	1.9a	0.6a

[a] Par-baked bread was baked for 6 min at 218°C, frozen at –30°C for 7 days, and thawed before the second baking. Second baking time was chosen based on the crust color of bread.
[b] *L** = lightness; *a** = redness-greenness; *b** = yellowness-blueness.
[c] Δ*H* = differential scanning calorimetry enthalpy.
[d] Values in the column within each flour followed by the same letters are not significantly different at $P < 0.05$.

TABLE IV
Characteristics of French Bread Baked from Par-Baked Bread with Different Initial Baking Temperatures[a,b]

Initial Baking		2nd Baking	Bread Vol	Crust Color	Crumb Characteristics					
					3 hr			48 hr		
Temp. (°C)	Time (min)	Time (min)	(mL)	(*L**)	Moisture (%)	Firmness (N)	Δ*H* (J/g)	Moisture (%)	Firmness (N)	Δ*H* (J/g)
Hard Red Spring Wheat										
Control	–	–	615a	48.6ab	47.5c	2.1b	0.6ab	36.1b	11.6a	2.3a
246	4	16	460b	49.2a	49.6b	2.5a	0.5b	41.5a	10.3b	1.9b
218	6	16	500b	47.7b	49.7ab	2.0bc	0.7ab	41.3a	7.9c	2.0ab
191	10	16	470b	49.1ab	49.7ab	1.8c	0.8ab	41.5a	6.7d	2.0ab
163	12	16	510b	49.7a	49.8a	1.5d	0.9a	41.4a	6.3d	1.9b
Rampart										
Control			610a	48.9a	48.7c	1.9b	0.6a	36.7c	11.6a	2.2a
246	4	16	460d	48.5a	50.1b	2.5a	0.6a	41.1b	9.8b	2.0a
218	6	16	500bc	47.5a	50.6a	1.9b	0.7a	41.9a	7.4c	2.0a
191	10	16	470cd	49.0a	50.3ab	1.7c	0.5a	41.5ab	6.8cd	2.0a
163	12	16	510b	49.2a	50.4ab	1.5c	0.7a	41.4ab	6.2d	1.8a

[a] Par-baked bread frozen at –30°C for 7 days after the initial baking and baked a second time for 16 min at 218°C without thawing.
[b] Values within each flour followed by the same letters in the same column are not significantly different at $P < 0.05$.

elimination of thawing time of frozen par-baked bread resulted in an increased crumb moisture content, suggesting that thawing may not be required for the second baking of frozen par-baked bread.

Effect of Baking Temperature on Preparation of Par-baked Bread

Par-baked bread was prepared by initially baking at different temperatures. Baking time selected for each baking temperature was equivalent to the time required for the bread crumb to reach 97°C. Bread crumb temperature reached 97°C with 4 min of baking at 246°C, 6 min at 218°C, 10 min at 191°C, and 12 min at 163°C (Fig. 1). Par-baked bread baked at various temperatures maintained its structure after cooling and exhibited little development of brown crust color. Par-baked bread stored at –30°C for 7 days was baked a second time without thawing at 218°C for 16 min and its quality characteristics were determined.

Table IV shows the characteristics of bread baked a second time from par-baked bread of HRS and Rampart with different initial baking temperatures and times. Compared with the control, breads prepared from par-baked breads were similar in crust color, smaller in loaf volume by >100 mL and higher in bread crumb moisture content by 1.4–2.3%. Crumb moisture content decreased by 11.4–12.0% in controls and by 8.1–9.0% in bread baked from par-baked bread during 48 hr of storage at 22°C. Consequently, bread baked from par-baked bread exhibited even higher crumb moisture content by 4.4–5.4% than the control after 48 hr of storage. Loaf volume and crust color of the bread baked a second time were not significantly different among par-baked bread of different initial baking temperatures in HRS. Variations in loaf volume of bread with different initial baking temperatures in Rampart were significant but relatively small and inconsistent. The lower the initial baking temperature of the par-baked bread, the less firm the crumb of the final bread was at both 3 hr and 48 hr after baking. Despite the lower loaf volumes and subsequently more compact bread crumb, bread baked a second time from par-baked bread, which was baked initially at <218°C, was comparable to or less firm than the control at 3 hr after baking. The differences in crumb firmness between the control and bread prepared from par-baked bread grew even bigger at extended storage time to 48 hr. Starch gelatinization enthalpies of the bread crumb were similar in breads of different initial baking temperatures and the control.

CONCLUSIONS

Par-baked French bread with comparable loaf volume and crumb structure to the fully baked bread is produced with baking time, corresponding to the time when crumb temperature reaches ≈97°C. Baking frozen par-baked bread without thawing results in higher crumb moisture content of the final bread than baking after thawing. Low temperature and long time baking for the preparation of par-baked bread tends to decrease the crumb firmness of the final bread.

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[Received March 17, 2006. Accepted May 9, 2006.]