Description and Application of an Experimental Heat Sink Oven Equipped with a Loaf Height Tracker for the Measurement of Dough Expansion During Baking[1]

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Cereal Chem. 67(5):443-447

ABSTRACT

An experimental heat sink oven equipped with a loaf height tracker was developed for the measurement of dough expansion during baking. The loaf height tracker consists of a Teflon pad attached to a movable stainless steel rod that passes through the heat sink and outer oven walls. The movement of the pad and rod in response to changes in loaf height during baking are measured electronically. The oven design gave excellent temperature control during the baking of remix-processed bread. This resulted in very good reproducibility of oven rise properties, including maximum loaf height and time to maximum loaf height. The effects of ascorbic acid and sodium stearoyl-2-lactylate (SSL) upon the properties of Brazilian-processed bread were also studied. The reduction in bread quality due to omission of SSL from the formula is attributed to the reduction in oven spring. The very large negative effects upon bread properties due to omission of ascorbic acid from the formula could be attributed to reduction of proofing height and a lack of oven spring.

INTRODUCTION

Oven spring can be defined as the rapid expansion of dough occurring during the early baking stage. This phenomenon is of primary importance in determining the loaf volume and textural characteristics of bread. However, few studies of oven spring have been reported in the literature.

In a series of papers published in 1939, Baker and co-workers (Baker 1939; Baker and Mize 1939a,b) reported studies on the effects of various ingredients and processing conditions on the oven-rise characteristics of straight doughs, using an electric heat-resistance oven. Under their conditions, oven rise occurred over a maximum period of 15 min after the proofed dough was placed in the oven. Addition of bromate was shown to induce a much faster rate of dough expansion over a longer period compared to unbromated doughs. Increasing shortening level or fermentation time also had significant positive effects upon dough expansion rates in the oven. Unfortunately, the electrical-resistance dough-heating method resulted in the formation of crustless bread. Thus, the effect of crust formation on oven rise properties could not be assessed. Recently Hoseney and co-workers (Junge and Hoseney 1981; Moore and Hoseney 1986a,b) have used a similar approach to the above. Their results showed that fat and surfactants increase the rate and time of dough expansion during baking.

Elton and Fisher (1966) used time-lapse photography to determine oven-rise characteristics in their study of the Chorleywood bread process. Their results showed that fat, and in particular the level of high-melting fat, was critical in obtaining good oven spring with this process.

In our laboratory we have been interested in developing laboratory-scale ovens and related instrumentation that automatically and reproducibly measure the expansion and contraction of baking bread without altering the properties of the final product. The development of this type of equipment would allow measurement of oven rise, oven spring, and loaf shrinkage during baking, ingredient, and processing (especially oven) conditions that affect these parameters and their relationship to bread quality. The present article describes a simple loaf height tracker used in conjunction with an experimental heat sink oven described previously (Kilborn and Tipples 1981a) that meets these objectives. The use of these devices is demonstrated by the measurement of remix and "Brazilian" dough expansion properties during baking. Emphasis is placed on reproducibility and ingredient (improver) effects.

MATERIALS AND METHODS

Wheat and Flour Properties

The No. 1 Canada western red spring (No. 1 CWRS) and No. 1 Canada prairie spring (No. 1 CPS) samples were obtained by blending wheat cargo samples obtained from Pacific export shipments of the same grade. The No. 1 CWRS sample was tempered to 16.5% for 18 hr, and the No. 1 CPS sample was tempered to 15.5% moisture for 18 hr before being milled to straight grade flour on the GRL pilot mill as previously described (Black 1980). Flour yields of approximately 76% (first break basis) were obtained for the No. 1 CWRS and approximately 75% were obtained for the No. 1 CPS.

Flour properties (Table I) were assessed by methods previously described (Preston et al 1988). All tests were done in duplicate.

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Values for selected quality characteristics of the flours are given in Table I.

Baking

The remix baking procedure (15 ppm of bromate) was used as previously described by Kilborn and Tipples (1981b). Bread was assessed for loaf volume (SD = 10 cm^3) and crumb and crust characteristics, including loaf appearance, crumb structure, and crumb color (SD = 0.2 units for each scoring procedure) as described by Preston et al (1982). Remix bread properties (average of duplicates) of the No. 1 CWRS and No. 1 CPS flours are given in Table I.

The Brazilian soft hearth bread formulation (including fat) was obtained by the authors during visits to Brazilian bakeries in 1984. The full formula included flour (500 g, 100%), salt (10.0 g, 2.0%), Fermipan dry yeast (6.1 g, 1.2%), sugar (8.0 g, 1.6%), shortening (10.0 g, 2.0%), malt flour (1.0 g, 0.2%), ammonium phosphate (0.58 g, 0.1%), sodium stearoyl-2-lactylate (1.0 g, 0.2%), ascorbic acid (0.035 g, 70 ppm), and optimum water absorption as assessed by dough feel at panning. The baking absorption of the No. 1 CPS wheat flour used in the present study was 55%. For processing, dough ingredients were mixed in a GRL 1000 mixer (Kilborn and Tipples 1974) to 10% past peak at 160 rpm. Doughs were then scaled to provide three pieces (262 g of dough = 160 g of flour per piece) and rounded by hand. The rounded doughs were immediately sheeted three times with roll gaps of 8.7, 4.8, and 3.2 mm through modified National 1-lb sheeting rolls (adjusted for a 13.2-mm width), and molded on the GRL molder as previously described (Kilborn and Preston 1982). After dough pieces were placed in tin pans (i.d. top: 11.5 × 16.5 cm; i.d. bottom: 9.0 × 13.0 cm; depth: 7.2 cm), final proofing was done for 2 hr at 33°C and 87% rh. Doughs were baked at 230°C for 25 min (Kilborn and Tipples 1981a) in the experimental heat sink oven equipped with a loaf height tracker as described below. For producing hearth bread, molded doughs (elongated by hand) were proofed 2 hr at 33°C on greased metal pizza pans, slit with a knife, and then baked in a hearth oven at 230°C for 25 min. Steam was injected into the oven during the first minute of baking. Hearth bread was also produced as described above except that doughs were sheeted and molded on a Perfecta Moulder model RT (Perfecta Ltd., Curitiba-Parana, Brazil) using position No. 4.

Description of Loaf Height Tracker

The design of the loaf height tracker is similar in principle to that of the GRL dough height tracker (Kilborn and Preston 1981). Changes in dough height during baking are measured by the vertical movement of a Teflon pad attached to a stainless steel rod that passes through the oven walls, as shown in the schematic diagram (Fig. 1). This vertical movement is converted to rotary motion through a line and pulley and measured as an electrical voltage by means of a potentiometer attached to the hub of the pulley. This electrical voltage drives an amplifier calibrated to produce full-scale deflection for 110-mm vertical movement of the Teflon pad. Dough height can be obtained from a printer, chart recorder, or digital panel meter after pan height has been calibrated using wooden blocks of known height. The instrument is also equipped with a device (Fig. 1; off-center cam) for automatically raising or lowering the Teflon pad; this device can be activated by a push button.

Description of Experimental Heat Sink Oven

The experimental heat sink oven consists of a stationary bake oven into which has been placed a heat sink reference oven as described previously (Kilborn and Tipples 1981a). The stationary bake oven was constructed of stainless steel outer (60 × 60 × 90 cm) and inner (40 × 40 × 70 cm) shells separated by insulation and equipped with a double-pane glass door (29 × 29 cm). The heat sink reference oven is mounted on a stainless steel mesh shelf located in the middle of the oven (Fig. 1). Heating is provided by two variable 750-W heaters mounted at the bottom of the bake oven. A two-speed fan is used to circulate air.

A control panel located under the oven allows control and monitoring of temperature by means of thermocouples located in the wall of the heat sink oven, inside the heat sink oven, or at other locations as desired. Controls are also present for adjusting fan speed, heater voltage, and loaf height tracker functions. Time, oven temperatures, heat consumption, and loaf height

TABLE I
Properties of Pilot-Milled Straight Grade Flours from No. 1 CWRS and No. 1 CPS Wheat Samples[a,b]

Property[c]	No. 1 CWRS	No. 1 CPS
Protein, %	13.8	10.8
Wet gluten, %	42.0	32.9
Ash, %	0.48	0.48
Farinograph absorption, %	65.2	55.9
Farinograph dough development time, min	4.50	4.50
Remix loaf volume, cm^3	900	740
Remix loaf appearance, units	7.4	7.0
Remix crumb structure, units	6.8	6.2
Remix crumb color, units	6.5	5.8
Remix water absorption, %	64	56

[a] Average of duplicate determinations.
[b] CWRS = Canada western red spring, CPS = Canada prairie spring.
[c] All values corrected to a 14.0% moisture basis.

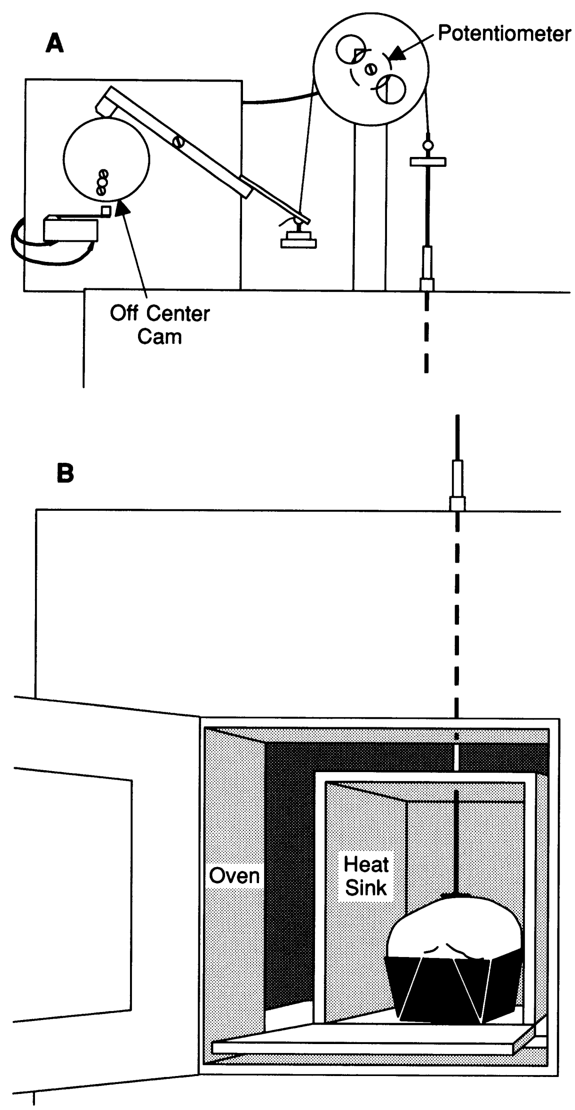

Fig. 1. Schematic diagram of heat sink oven equipped with loaf height tracker. **A,** Loaf height tracker mounted on top of oven; **B,** Heat sink oven showing heat sink and steel rod of tracker through oven.

characteristics can be monitored using internal printers or external devices from signals generated through the control panel. A schematic diagram of the electronic controls is given in Fig. 2.

Experimental Design

Three experimental heat sink ovens equipped with loaf height trackers were used in the present study. Proofed doughs prepared by the various baking procedures were placed in the heat sink oven. The Teflon pad of the tracker was automatically lowered to the surface of the dough, and the change in dough height was recorded during the baking process. Time and temperature (from thermocouples located in the wall of the heat sink oven) were also recorded. All experiments were made using blocked factorial designs (blocked by day). Results were analyzed by analysis of variance (ANOVA) procedures using Stat-Packets, version 1.0 (Walonic Associates, Minneapolis) with Lotus 1-2-3 (Lotus Development Corporation, Cambridge, MA) data files on an IBM-AT computer. Data were compared for significant differences by Duncan's multiple range test.

RESULTS AND DISCUSSION

An experimental oven containing a heat sink was chosen for studies of dough expansion during baking, using the loaf height tracker. The major reason for this choice was the demonstrated ability of heat sink ovens to provide much more uniform baking conditions and superior reproducibility of products than traditional ovens (Kilborn and Tipples 1981a). The experimental oven design also offered better control over the choice of experimental conditions and output of results. Figure 3 demonstrates the excellent temperature control afforded by the oven for 12 replicates of remix-processed doughs prepared from the No. 1 CWRS wheat flour (Table 1). The average temperature of the heat sink oven ranged from 226 to 230°C, with standard deviations averaging approximately 2°C during 25 min of baking at a setting of 230°C.

Oven Rise Properties of Remix-Processed Bread

The No. 1 CWRS wheat flour was processed by the remix baking procedure (Kilborn and Tipples 1981b) to demonstrate the application of the loaf height tracker. In some cases the Teflon pad caused a slight depression on the top of baked loaves. However, use of the loaf height tracker in conjunction with the experimental heat sink oven had no noticeable effect upon final overall bread properties compared to use of the standard baking procedure.

Figure 4 shows the curve obtained for loaf height (average and standard deviation for 12 replicates) during 25 min of baking at 230°C, with height measured at 1-min intervals. As illustrated by the curve, standard deviations for loaf height measurement showed low values (1.4–1.9 mm), indicating very good reproducibility. From an average proof height of 103 ± 1.6 mm, very rapid expansion (10 cm) occurred during the first minute of baking, followed by further rapid expansion, averaging 4 cm/

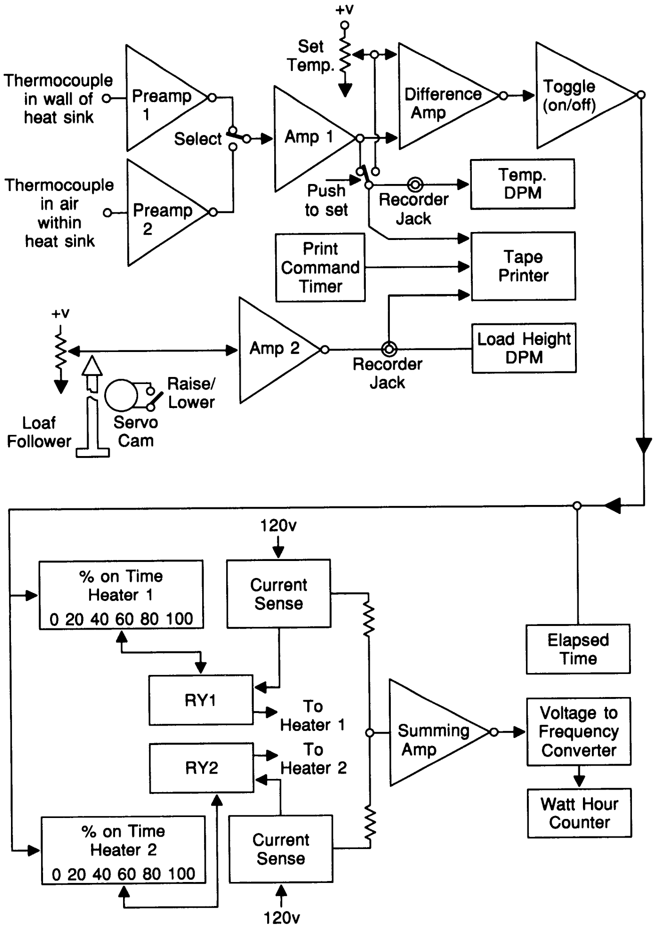

Fig. 2. Electronic controls for heat sink oven and loaf height tracker.

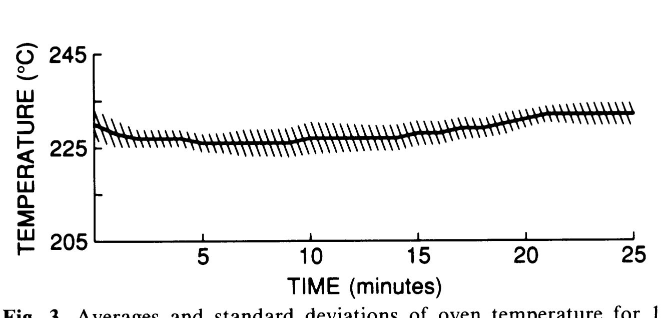

Fig. 3. Averages and standard deviations of oven temperature for 12 replicates of remix-processed bread (No. 1 Canadian western red spring wheat flour) using the heat sink oven. Oven temperature was set at 230°C, and temperature of the heat sink walls was measured every 1 min for 25 min.

TABLE II
Effects of Oven, Day, and Daily Replication on Time to Maximum Loaf Height of Remix Bread[a,b]

Oven No.	Time (min)	Day No.	Time (min)	Daily Replicate No.	Time (min)
1	8.1 ± 1.4	1	8.3 ± 1.3	1	8.3 ± 1.2
2	7.8 ± 0.5	2	8.3 ± 1.2	2	7.8 ± 1.3
3	7.9 ± 1.2	3	7.4 ± 0.7	3	7.7 ± 0.6
		4	7.6 ± 0.7		

[a] Values represent mean ± standard deviation for 12, nine, and 12 determinations for ovens, days, and daily replications, respectively.
[b] No significant differences detected between any group of means at the 5% level ($P < 0.05$).

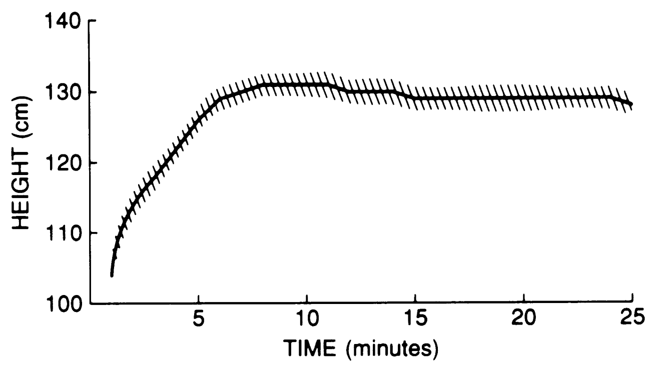

Fig. 4. Averages and standard deviations of loaf height for 12 replicates of remix-processed bread (No. 1 Canadian western red spring wheat flour) using the heat sink oven. Oven temperature was set at 230°C, and loaf height was measured every 1 min for 25 min.

TABLE III
Effects of Oven, Day, and Daily Replication on Maximum Loaf Height of Remix Bread[a]

Oven No.	Maximum Loaf Height[b] (mm)	Day No.	Maximum Loaf Height (mm)	Daily Replicate No.	Maximum Loaf Height (mm)
1	126.8 ± 2.3 a	1	129.6 ± 2.3 a	1	128.8 ± 2.9 a
2	130.3 ± 1.7 b	2	128.4 ± 3.0 a	2	130.0 ± 2.1 a
3	130.1 ± 1.4 b	3	129.7 ± 2.1 a	3	128.4 ± 2.2 a
		4	128.6 ± 2.4 a		

[a]Values represent mean ± standard deviation for 12, nine, and 12 determinations for ovens, days, and daily replications, respectively.
[b]Different letters signify significant differences at the 1% level ($P < 0.01$).

TABLE IV
Effect of Treatment on "Brazilian" Pan Bread Properties[a]

Treatment[b]	Loaf Volume[c] (cm^3)	Appearance	Crumb Structure	Crumb Color
AA + SSL	1,861 ± 54 a	7.9 ± 0.2 a	6.5 ± 0.1 a	9.0 ± 0.1 a
AA	1,699 ± 33 b	6.5 ± 0.0 b	5.9 ± 0.1 b	8.5 ± 0.1 b
SSL	1,268 ± 45 c	2.0 ± 0.0 c	3.0 ± 0.0 c	4.0 ± 0.0 c

[a]Values represent mean ± standard deviation for 18 determinations.
[b]AA = ascorbic acid, SSL = sodium stearoyl-2-lactylate.
[c]Different letters signify significant differences at the 1% level ($P < 0.01$).

min, over the next 4 min. Maximum loaf height (130 ± 1.5 mm) was attained after 8 min. This last value is similar to that obtained by Elton and Fisher for nonfat Chorleywood-processed bread. During further baking, a small but significant ($P < 0.01$) decrease in loaf height occurred, indicating shrinkage.

Further (factorial) experiments were made using three experimental ovens equipped with loaf height trackers to determine the reproducibility between ovens, days (blocks), and daily replication sequence. Results are shown in Tables II and III for time to maximum loaf height and maximum loaf height, respectively. ANOVA analysis showed no significant effects for time to maximum loaf height due to ovens, days, or daily replication sequence (Table II). There was also no significant effect upon maximum loaf height due to days or daily replication sequence (Table III). However, a significant ($P < 0.01$) effect was found due to ovens. This effect could be attributed to the lower temperature of the heat sink attained with one of the ovens due to lower heater capacity.

Properties of Brazilian-Processed Bread

One of the most common types of bread in Brazil, soft hearth, is normally produced by a "short" straight dough process that relies upon proprietary additives and fat to obtain the desired loaf characteristics. These characteristics include high specific volume (normally greater than 8 cm^3/g), a crisp crust, and a fine white crumb structure (Dexter et al 1985). Discussions with Brazilian millers and bakers and analysis of their improvers in our laboratory indicated that the most common additives contain ascorbic acid and sodium stearoyl-2-lactylate (SSL) (unpublished data). The use of bromate as a bread improver is not allowed in Brazil.

Preliminary studies were done to determine the effect of these ingredients, using three baking procedures with a No. 1 CPS wheat flour (Table I). All procedures were identical until the sheeting and molding stage and involved formulation and processing procedures that mimicked, as closely as possible, conditions used in Brazil. In the first procedure, a Brazilian molder was used to produce hearth bread similar in shape to *pao frances*. In the second procedure, a National sheeter and GRL molder were used to produce hearth bread. The third procedure was identical to the second until after the molding stage, when the doughs were proofed and baked in pans. All three procedures gave very similar results in terms of specific volume, crumb color, and crumb texture at corresponding additive formulations (70 ppm ascorbic acid, 0.2% SSL). These results indicated that sheeting and molding technique and baking procedure (hearth versus pan) had minimal effects upon these parameters (data not shown).

The effects of these additives upon bread and oven rise properties were then further studied by factorial ANOVA experiments using the "Brazilian" pan bread procedure and three experimental ovens equipped with loaf height trackers. Data obtained for bread properties are given in Table IV. In the presence of ascorbic acid (70 ppm) and SSL (0.2%), bread of high volume (average specific volume = 8–9 cm^3/g), very good appearance and crumb color, and satisfactory crumb structure (basis Brazilian requirements) were obtained. Omission of SSL from the formulation resulted in a large (9%) significant ($P < 0.01$) decrease in loaf volume and significant ($P < 0.01$) decrease in crumb and crust characteristics. The results are consistent with the well-known improver effects of SSL (Bruinsma and Finney 1984, Chung and Pomeranz 1977). Omission of ascorbic acid from the formulation had a much more dramatic effect upon bread properties than the omission of SSL. Loaf volume decreased 32% compared to that obtained with the full formula, and very low scores were obtained for crumb and crust characteristics. All values were significantly different ($P < 0.01$) from corresponding values obtained in the presence of SSL plus ascorbic acid or ascorbic acid alone. The dramatic effect of ascorbic acid omission upon the bread properties can be attributed to the central role played by oxidation in the baking process (Tsen 1964). This effect has been shown to be compounded further in processes involving short fermentation times (Finney et al 1976, Kilborn and Tipples 1979).

Table V shows the effects of the improvers upon oven rise properties of the bread described above. Omission of SSL from the full formula had no significant effect upon proof height. However, significant ($P < 0.01$) reductions in maximum loaf height and oven spring (maximum loaf height minus proof height) were obtained. These results are consistent with previous studies showing that fats and surfactants exert their effects at the oven stage and have minimal effect upon proofing (Bell et al 1977, Moore and Hoseney 1986b). Omission of ascorbic acid from the formulation had significant ($P < 0.01$) negative effects upon both proof height and oven rise properties. The large decrease in proof height is probably associated with a decrease in the gas retention properties of the underoxidized dough, as shown previously by Marek et al (1968). The inability of the dough to retain gas may also account for the almost complete lack of oven spring in the absence of ascorbic acid.

The time required for the Brazilian pan bread dough to attain maximum oven height (Table V) was much shorter than the corresponding time required for the remix procedure (Table II) or for Chorleywood-processed bread (Elton and Fisher 1966). No explanation can be offered at the present time to account for these differences. Omission of SSL had no significant effect on time to maximum loaf height compared to the time obtained with the full formulation. However, removal of ascorbic acid did show a significant ($P < 0.01$) effect upon this parameter.

CONCLUSIONS

The experimental heat sink ovens gave excellent temperature control during baking. Average temperatures obtained at 1-min intervals during the 30-min baking period for remix-processed bread ranged from 226 to 230°C at a control setting of 230°C.

TABLE V
Effect of Treatment on Oven Rise Properties of "Brazilian" Pan Bread[a]

Treatment[b]	Proof Height[c] (mm)	Maximum Loaf Height (mm)	Time to Maximum Loaf Height (min)	Oven Spring[d] (mm)
AA + SSL	109.6 ± 4.1 a	136.9 ± 5.5 a	3.8 ± 0.8 a	27.3 ± 7.0 a
AA	107.8 ± 2.9 a	124.7 ± 3.6 b	3.3 ± 1.0 a	16.9 ± 3.3 b
SSL	94.4 ± 4.5 b	96.0 ± 3.5 a	1.9 ± 0.8 b	1.6 ± 4.8 c

[a] Values represent mean ± standard deviation for 18 determinations.
[b] AA = ascorbic acid, SSL = sodium stearoyl-2-lactylate.
[c] Different letters signify significant differences at the 1% level ($P < 0.01$).
[d] Oven spring = maximum oven height − proof height.

The importance of proper oven temperature control in improving the reproducibility of bread characteristics is well known (Kilborn and Tipples 1981a).

The loaf height tracker, used in conjunction with the experimental heat sink ovens, gave very good reproducibility of oven rise characteristics of remix-processed bread made with a No. 1 CWRS wheat flour. Coefficients of variability for maximum oven loaf height attained during baking averaged 1.7%, and corresponding values for time to maximum oven height averaged 13%. Maximum loaf height was attained after an average of 7.9 min, a value similar to that obtained using the Chorleywood process (Elton and Fisher 1966).

The effects of ascorbic acid and SSL on the oven rise and bread characteristics of Brazilian-processed bread were assessed using a No. 1 CPS wheat flour. The omission of ascorbic acid or SSL from the formula resulted in significant negative effects upon loaf volume and crumb and crust characteristics. The effects of ascorbic acid omission were more pronounced than those of SSL omission. The reduction in bread quality due to omission of SSL could be directly attributed to a reduction in oven spring. The omission of ascorbic acid reduced proof height and almost completely inhibited oven spring. These latter effects can probably be attributed to a large reduction in the ability of the dough to retain gas due to lack of oxidation.

ACKNOWLEDGMENTS

We gratefully acknowledge the expert technical assistance of G. Paulley, E. Gander, E. Mydlo, I. Phillips, and C. Taplin.

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[Received September 29, 1989. Accepted March 27, 1990.]