Sponge-and-Dough Bread: Effects of Oxidants on Bread and Oven Rise Properties of a Canadian Red Spring Wheat Patent Flour[1]

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ABSTRACT

The effects of increasing levels of azodicarbonamide, ascorbic acid, bromate, and L-cystine on the sponge-and-dough bread and oven rise properties of a Canadian hard red spring wheat patent flour were studied. Loaf volumes and bread scores increased with increasing levels of all four of the oxidants until optimum levels were attained. The amount of ascorbic acid or L-cystine required to obtain optimum bread properties was higher than that of bromate or azodicarbonamide. Ascorbic acid and L-cystine also showed a wider range of addition over which optimum bread properties could be maintained. No significant differences were evident in bread score among the oxidants, although bromate gave a somewhat ($P < 0.05$) higher loaf volume. Maximum oven rise during baking was closely associated with loaf volume and bread scores. Differences in oven rise could be attributed primarily to differences in oven rise time. Rates of oven rise (mm/min) during the first three minutes of baking, when rates were highest, were generally independent of treatment.

Addition of oxidative improvers at optimum levels normally results in improved dough-handling properties and bread quality. The most commonly used oxidative improvers include ascorbic acid (AA), azodicarbonamide (ADA), and bromate. The use of the latter is declining due to legislation restricting or banning its use and to increasing consumer resistance to its presence in bread formulations.

Previous evidence suggested that the bread-improving effects associated with oxidants can be attributed to their action on gluten proteins, resulting in increased gas retention properties (Bloksma and Bushuk 1988). These improving effects are most evident in the oven, where oxidation increases oven rise (Baker and Mize 1939a,b; Kilborn et al 1990; Yamada and Preston 1992). Studies by Baker and Mize (1939a,b) showed that addition of bromate increased both the rate of oven rise and the time during which oven rise occurred for straight doughs baked in an electrical-resistance oven. Recent studies in our laboratory with short process bread (Yamada and Preston 1992) indicated that the oven rise time factor was primarily responsible for increased oven rise for the four oxidants (ADA, AA, iodate, and bromate) tested in that study. All the oxidants gave similar oven rise profiles and were equally effective in improving bread quality at optimum levels.

The sponge-and-dough bread processing method is used extensively in North America and in Asian countries, such as Japan and South Korea. This study assessed the effects of commonly used oxidants (ADA, AA, and bromate) on sponge-and-dough bread properties and oven rise characteristics of a patent Canadian red spring wheat flour, using Japanese formulation and processing conditions. The use of L-cystine as a potential oxidative improver was also investigated on the basis of previous findings by Nagao (1985).

MATERIAL AND METHODS

Flour Properties

Short patent flour was milled on the Grain Research Laboratory (GRL) pilot mill from a No. 1 Canada Western Red Spring (CWRS) wheat as described previously (Black 1980). The flour had an ash content of 0.36% (AACC 1983), a protein content of 11.7% (Williams 1973), basis moisture content of 14.0% (AACC 1983).

Baking and Measurement of Oven Rise Properties

Bread was produced using a laboratory sponge-and-dough procedure with formulation and processing conditions similar to those used in Japan (Kilborn and Preston 1981, Preston and Kilborn 1982). Sponge ingredients included flour (70 g), compressed yeast (2.0 g), salt (0.15 g), ammonium phosphate (0.1 g), 60°L malt syrup (0.2 g), and water (2% below optimum dough absorption). Sponge ingredients were mixed for 2.5 min in a GRL-200 mixer at 135 rpm (27°C), then fermented for 270 min at 27°C (90% rh) in greased, glazed crockery bowls placed in a fermentation cabinet. The sponge and remaining ingredients (30 g of flour, 2.25 g of salt, 5.0 g of sucrose, 3.0 g of shortening, 2.0 g of skim milk powder, and 0.1 g of malt syrup) were then mixed at optimum absorption, based on dough feel at panning (64% for all oxidant treatments) to ~10% past peak mixing time in a GRL-200 mixer (30°C). After a 15-min rest period, doughs were punched, rested a further 15 min, sheeted and molded, and then panned. After proofing for 70 min at 38°C, doughs were baked at 195°C for 24 min in a heat-sink oven equipped with a loaf-height tracker to continuously measure oven rise (Kilborn et al 1990). The four oxidants were added to the sponge over a range of levels to determine response curves and optimum levels for each. Loaf volumes, crumb and crust characteristics, and bread scores were determined as previously described (Preston and Kilborn 1982).

Oven rise parameters measured during baking included: a, maximum oven rise (the maximum loaf height attained minus initial [proofed] height); b, oven rise time (the time required to attain maximum oven rise); c, rate of oven rise (the change in loaf height per minute during baking).

Experimental Design

A randomized block design was used to assess the effects of increasing oxidant level for each oxidant. Experiments were conducted using six blocks separated by time. After optimum levels for each oxidant were determined, a separate experiment, using the same experimental design, was conducted to compare their relative effects on baking quality and oven rise properties. An untreated dough (no oxidant) was included in all experiments.

Data were analyzed using SAS Stat Release 6.03 for microcomputers (SAS Institute, Cary, NC). Results are reported as an average of six replicates (blocks) from analysis of variance analysis. Appropriate values were compared for significant differences at the 5% level using Duncan's multiple range test.

RESULTS

The ingredients and processing conditions used in this study were determined on the basis of discussions with Japanese millers

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and bakers (Preston and Kilborn 1982). A CWRS patent flour, similar to that employed in Japan, was used to produce the laboratory scale white pan (open top) sponge-and-dough bread. Heat-sink ovens equipped with loaf-height trackers were used to bake the bread and measure oven properties. Previous studies have shown that this equipment allows measurement of oven rise parameters without affecting bread characteristics and reduces random variability among and between bakes due to improved temperature control (Kilborn et al 1990, Yamada and Preston 1992).

Effects of Oxidants on Bread Quality

The effects of increasing levels of the four individual oxidants (AA, ADA, bromate, and L-cystine) on loaf volume and total bread score are shown in Tables I and II, respectively. Addition of increasing levels of all oxidants increased loaf volume and bread score until optimum values were attained. Higher amounts of AA (10–15 ppm) and L-cystine (20 ppm) were required to achieve optimum baking quality compared to the amounts required with ADA (5 ppm) and bromate (5–10 ppm). The range over which each oxidant could be added to obtain optimum bread quality varied. Consistent with previous studies (Tsen 1964, Yamada and Preston 1992), AA showed the greatest tolerance with no significant ($P < 0.05$) difference in loaf volume or bread score from 15 to 150 ppm (the highest level tested). Bromate and ADA showed a lower range (~10 ppm) of addition for optimum loaf volume and bread score than did L-cystine (~20 ppm), indicating that bread properties are more tolerant to addition of L-cystine. Addition of oxidant above optimum levels resulted in decreased bread quality (volume and score).

Loaf appearance, crumb structure, and crumb color showed trends similar to that of bread score (data not shown). The differences that were sometimes evident between the levels of oxidant required for optimum loaf volume response and optimum bread score could be attributed to differential response among these parameters (i.e., loaf volume versus crust and crumb characteristics). Proof height (data not shown) was similar for all treatments and was therefore not related to loaf volume, bread score, or oven rise characteristics.

Table III shows a comparison of the effects of oxidants at optimum level on loaf volume and bread score. At optimum level, all oxidants gave similar bread scores, but bromate gave a slightly higher loaf volume ($P < 0.05$) than that of the other improvers. With no oxidant, loaf volume and bread scores were significantly lower ($P < 0.05$).

Effect of Oxidants on Oven Rise Properties

The effects of increasing levels of individual oxidants on maximum oven rise and oven rise time in the heat-sink ovens are shown in Tables IV and V, respectively. Maximum oven rise and oven rise time increased with increasing levels of each oxidant, until optimum levels were obtained. Values for both parameters showed the same general trend as results obtained for loaf volume and bread score. Lower levels of bromate and ADA were required to obtain maximum values compared to that required of L-cystine and AA; the latter (particularly AA) showed a wider range of addition over which maximum values were obtained. Oxidant levels over which the highest values were obtained for maximum oven rise generally showed a narrower range than that of corresponding levels over which the highest values were obtained for oven rise time. These differences may be partly due to the higher accuracy (lower coefficient of variability) obtained in measuring maximum oven rise compared to that of measuring oven rise time. Variation in the rate of oven rise may also contribute to these differences.

Values obtained for maximum oven rise and oven rise time at optimum oxidant levels were much higher ($P < 0.05$) than values obtained with no oxidant (Table III). Bromate showed significantly ($P < 0.05$) higher values for both parameters compared to the values of AA and L-cystine and significantly higher value for oven rise compared to that of ADA. These higher values were consistent with the higher loaf volume obtained with bromate.

Table VI shows the rate of oven rise for doughs treated either

TABLE I
Effects of Increasing Levels of Ascorbic Acid (AA), Azodicarbonamide (ADA), Potassium Bromate, and L-Cystine on Sponge-and-Dough Loaf Volume[a]

AA		ADA		Bromate		L-Cystine	
Level (ppm)	Volume (cc)	Level (ppm)	Volume (cc)	Level (ppm)	Volume (cc)	Level (ppm)	Volume (cc)
0	947 c	0	934 c	0	945 e	0	959 c
5	973 b	5	970 a	5	993 bc	10	995 b
10	988 a	10	974 a	10	1,008 a	20	1,010 a
15	994 a	15	973 a	15	998 ab	30	1,014 a
20	988 a	20	967 a	20	989 bc	40	1,013 a
50	987 a	25	955 b	25	998 ab	50	1,018 a
100	991 a			30	993 bc	60	1,013 a
150	993 a			35	983 cd		
				40	974 d		

[a] Values represent average of six blocks. Different letters indicate significant differences at the 5% level.

TABLE II
Effects of Increasing Levels of Ascorbic Acid (AA), Azodicarbonamide (ADA), Potassium Bromate, and L-Cystine on Sponge-and-Dough Bread Score[a]

AA		ADA		Bromate		L-Cystine	
Level (ppm)	Score (units)	Level (ppm)	Score (units)	Level (ppm)	Score (units)	Level (ppm)	Score (units)
0	65 d	0	64 d	0	65 cd	0	66 c
5	2 c	5	76 ab	5	76 a	10	73 b
10	5 bc	10	82 a	10	76 a	20	80 a
15	80 ab	15	74 ab	15	73 ab	30	76 ab
20	77 a–c	20	72 bc	20	69 bc	40	77 ab
50	81 ab	25	66 cd	25	69 bc	50	74 b
100	82 a			30	63 de	60	67 c
150	81 ab			35	59 e		
				40	52 f		

[a] Values represent average of six blocks. Different letters indicate significant differences at the 5% level.

at optimum oxidant levels or with no oxidant. Values are given for the change in dough height for each of the 6 min during which expansion occurred. Rates of oven rise reached maximum values during the second minute of expansion and decreased rapidly after the third minute. At optimum oxidation levels, rates were generally not significantly different among oxidants during each of the first five minutes. In the sixth minute, bromate showed a higher rate ($P < 0.05$) of oven rise than did AA and L-cystine. With no oxidant, rates during the first two minutes of baking were not significantly different than rates obtained at optimum levels of oxidant. During the third minute, the rate for no oxidant was somewhat lower ($P < 0.05$) than the rate with oxidant. After three minutes, the no oxidant rate was much lower. Results obtained with increasing levels of oxidants showed similar trends in rates of oven rise (data not shown). For each oxidant, rates showed maximum values during the second minute, regardless of treatment level. Rates during each of the first three minutes did not generally show significant differences among treatment levels. However, after the third minute, underoxidized doughs showed reduced rates compared to those obtained with optimum values, while overoxidized doughs showed lower rates in the sixth minute. These same trends were shown previously for doughs prepared using a short process (Yamada and Preston 1992).

DISCUSSION

Addition of increasing amounts of the four oxidants (AA, ADA, bromate, and L-cystine) to sponges containing Canadian red spring wheat patent flour resulted in improved sponge-and-dough loaf volume, crust and crumb characteristics, and bread score. Levels of bromate (5–10 ppm) and ADA (5 ppm) required to optimize bread characteristics were lower than levels required with AA (15 ppm). However, AA showed a much wider range of addition (15–150 ppm) over which optimum properties could be maintained than did bromate (5–15 ppm) and ADA (5–15 ppm). These trends are generally consistent with previous studies using straight doughs (Cathcart and Edelmann 1944, Tsen 1964) and "no-time" doughs (Yamada and Preston 1992). However, levels of individual oxidants required to attain optimum bread properties were higher in previous studies (especially with no-time doughs) than those reported here. These differences are most likely associated with the reduction in oxidation requirement associated with the long sponge-fermentation time (Preston and Kilborn 1982) and the use of low ash patent flour (Dempster et al 1956).

No significant differences were evident in bread score among the four oxidants at optimum levels, although bromate gave a somewhat higher ($P < 0.05$) loaf volume than did the other additives. This could be attributed to the higher maximum oven rise of bromate due to longer oven rise time. These results are generally similar to those obtained previously with no-time doughs (Yamada and Preston 1992) using the same oxidants (bromate, ADA, AA) as well as iodate. The only exception was that bromate did not increase loaf volume (and did not show longer oven rise time) than did the other oxidants with the no-time process. The difference in bromate response, compared to the other oxidants for the two different processes, is difficult to explain. It may be a result of bromate's demonstrated ability to survive during processing until high temperatures are attained in the oven (Cunningham and Anderson 1956, Dempster et al 1956). This would allow bromate to exert its effect after long fermentation periods, when other oxidants have completely reacted. This is consistent with recent studies in our laboratory (unpublished data) indicating that oxidants such as ADA and AA are most effective when added to the dough, while bromate is most effective when added to the sponge.

Results of this study indicate that L-cystine is an effective oxidant in the production of sponge-and-dough bread, as suggested previously by Nagao (1985). The level of this ingredient required to attain optimum bread quality appears to be higher than that of the other oxidants tested. Doughs also show an apparently greater tolerance to the addition of L-cystine than they do to bromate and ADA, but they show less tolerance when

TABLE III
Effects of Oxidants at Optimum Levels on Bread and Oven Rise Properties[a]

Oxidant	Level (ppm)	Volume[b] (cm^3)	Score	Maximum Oven Rise (mm)	Oven Rise Time (min)
No oxidant	0	975 c	66 b	22.3 d	4.3 d
ADA[c]	10	1,008 b	85 a	27.3 b	5.8 ab
AA[d]	15	1,004 b	84 a	26.3 c	5.3 c
Bromate	5	1,028 a	85 a	28.7 a	6.1 a
L-cystine	20	1,010 b	83 a	26.2 c	5.5 bc

[a] Values represent average of six blocks. Different letters indicate significant differences at the 5% level.
[b] Volume obtained from 100 g of flour.
[c] Azodicarbonamide.
[d] Ascorbic acid.

TABLE IV
Effects of Increasing Levels of Ascorbic Acid (AA), Azodicarbonamide (ADA), Potassium Bromate, and L-Cystine on Sponge-and-Dough Maximum Oven Rise[a]

AA		ADA		Bromate		L-Cystine	
Level (ppm)	Rise (mm)	Level (ppm)	Rise (mm)	Level (ppm)	Rise (mm)	Level (ppm)	Rise (mm)
0	19.3 c	0	22.0 c	0	18.8 f	0	19.0 b
5	20.0 bc	5	26.5 a	5	26.8 a–c	10	23.4 a
10	21.3 ab	10	26.8 a	10	27.0 ab	20	24.4 a
15	22.7 a	15	26.0 a	15	27.7 a	30	25.0 a
20	22.7 a	20	25.0 ab	20	26.2 b–d	40	24.6 a
50	22.3 a	25	23.3 bc	25	26.2 b–d	50	25.0 a
100	22.5 a			30	25.0 d	60	24.6 a
150	22.2 a			35	25.5 cd		
				40	23.5 e		

[a] Values represent average of six blocks. Different letters indicate significant differences at the 5% level.

TABLE V
Effects of Increasing Levels of Ascorbic Acid (AA), Azodicarbonamide (ADA), Potassium Bromate, and L-Cystine on Sponge-and-Dough Oven Rise Time[a]

AA		ADA		Bromate		L-Cystine	
Level (ppm)	Time (min)	Level (ppm)	Time (min)	Level (ppm)	Time (min)	Level (ppm)	Time (min)
0	4.3 c	0	4.6 c	0	4.4 c	0	4.0 c
5	4.8 bc	5	5.6 ab	5	5.8 b	10	5.1 b
10	5.0 ab	10	6.3 a	10	6.0 ab	20	5.2 b
15	5.2 ab	15	6.1 a	15	6.4 ab	30	5.5 ab
20	5.2 ab	20	5.1 bc	20	6.7 a	40	6.0 a
50	5.4 a	25	5.6 ab	25	5.8 b	50	5.4 b
100	5.6 a			30	6.1 ab	60	5.6 ab
150	5.4 a			35	6.3 ab		
				40	6.3 ab		

[a] Values represent average of six blocks. Diffrent letters indicate significant differences at the 5% level.

TABLE VI
Effect of Oxidants at Optimum Levels on the Rate of Oven Rise[a]

Oxidant	Level	0–1 min	1–2 min	2–3 min	3–4 min	4–5 min	5–6 min
No oxidant	0	4.3 a	9.8 a	5.7 b	1.8 b	0.7 b	0.0 d
ADA[b]	10	3.5 b	9.8 a	7.0 a	3.8 a	2.0 a	1.2 ab
AA[c]	15	3.8 ab	8.3 a	7.3 a	4.0 a	1.8 a	0.7 c
Bromate	5	4.3 a	8.8 ab	8.2 a	4.0 a	1.7 a	1.5 a
L-cystine	20	4.0 ab	9.2 ab	7.2 a	3.3 a	1.5 a	1.0 bc

[a] Values represent average of six blocks. Different letters indicate significant differences at the 5% level.
[b] Azodicarbonamide.
[c] Ascorbic acid.

compared to AA. It should be noted that when L-cystine was used as an oxidant in the no-time process, this ingredient was ineffective (unpublished data). The reasons for this disparity are being investigated.

The classic studies of Baker and Mize (1939a,b) showed that loaf volume and other bread properties are closely associated with oven rise characteristics during the early baking stage. The increase in loaf volume (and improvement of bread characteristics) associated with increasing levels of the four oxidants used in the present study were also closely associated with increased maximum oven rise. These latter increases could be attributed primarily to an increase in the time during which oven rise occurred. In contrast, rates of oven rise (mm/min) were generally independent of treatment during the first three minutes when values were highest. The close positive relationship between maximum oven rise and oven rise time, and the lack of relationship between them and the rates of oven rise, is consistent with previous studies involving the effects of oxidants on the baking properties of no-time doughs (Kilborn et al 1990, Yamada and Preston 1992), but it contrasts with the studies of Baker and Mize (1939a,b), who noted that the improving effect of bromate on the loaf volume of straight doughs was due to an increase in both oven rise time and rate. However, their results were obtained using an electric heat-resistance oven in which the whole dough mass is uniformly heated and crustless bread is produced.

It should be emphasized that the present studies were performed under carefully controlled laboratory conditions, which included gentle handling of doughs. In commercial processing situations, conditions may not be as carefully controlled, and doughs may be subjected to less gentle handling. These factors could influence the relative effectiveness of these oxidants. With the increasing emphasis on oxidant systems excluding bromate, studies of the effects of these factors are urgently required.

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