Effect of Zinc and Aluminum Ions in Breadmaking[1]

Keswara Rao Vadlamani[2] and Paul A. Seib[2,3]

ABSTRACT

Cereal Chem. 76(3):355–360

Zinc and aluminum ions as chloride or sulfate salts at 50–500 ppm metal ion (flour basis) had no detrimental effect on fermentation of yeast-leavened dough. Increased mixing times (≈10–50%) due to addition of aqueous solutions of zinc (250–500 ppm) or aluminum (150–250 ppm) ions to a bread formula was overcome by withholding salt until the final mixing stage. Breads made from commercial flours (12.5% protein) containing zinc (250–500 ppm) or aluminum (150–250 ppm) ions and no oxidant had improved loaf volume and crumb grain when compared with control bread, and no off-taste. Additionally, breads with added zinc or aluminum had better crumb grains and slower firming rates when compared with breads containing optimum L-ascorbic acid (50 ppm) or potassium bromate (20 ppm). Breads made from commercial flours (11.1% protein) and three laboratory flours (11.4–13.6% protein) containing zinc (250 ppm) or aluminum (150 ppm) ions also had improved loaf volumes and crumb grains. Zinc or aluminum ions in combination with L-ascorbic acid, but not potassium bromate, had a detrimental effect on bread quality. Scanning electron microscopy of freeze-dried bread doughs revealed that zinc and aluminum ions enhanced the film-coating property of gluten. One serving (one slice, 28 g) of bread made with 250 ppm zinc ion would provide 25% of the adult recommended dietary allowance of zinc.

White pan bread should have a high specific loaf volume and good to excellent crumb grain. Bread crumb with uniformly small elongated gas cells is rated superior to bread crumb with large rounded cells, and fine grain usually has relatively thin cell walls as compared with coarse grain (Kamman 1970). Surfactants (Junge et al 1981, Hoseney 1984) and oxidants (Ranum 1992) are the most common improvers of volume and crumb grain used in breadmaking. Oxidants strengthen the gluten matrix in dough, while surfactants increase the number of gas cells that nucleate dough during mixing (Hoseney 1984). The increased number of cells improves both volume and crumb grain.

Finney et al (1992) added copper and zinc salts as possible oxidizing agents in breadmaking. Inclusion of 7.45 ppm of cupric chloride, sulfate, and nitrate in a bread formula was as effective as 50 ppm of L-ascorbic acid in improving loaf volume and crumb grain (Finney et al 1992). However, adding zinc ion as chloride or sulfate at a 2.4- to 24-ppm level had no effect on loaf volume and crumb grain. Holmes and Hoseney (1987) studied the effect of leavening salts such as sodium aluminum phosphate (SALP), sodium aluminum sulfate (SAS), and potassium aluminum sulfate (PAS) in yeast-leavened bread and reported that the phosphate and potassium ions of SALP and PAS reduced the ability of dough to retain gas, which decreased loaf volume.

The objective of our investigation was to determine the effects of zinc and aluminum ions on loaf volume and crumb grain of white pan bread and also determine effects on dough mixing and crumb firming.

MATERIALS AND METHODS

Flour

Two commercial bread flours (A and B) were obtained from Cargill Flour Milling Division (Wichita, KS) and three laboratory flours (Comp 1, 2, and 3) were milled (72% extraction) from composites of hard winter wheats in the Wheat Quality Testing Laboratory, Kansas State University (Manhattan, KS). Instant yeast (Fermi-pan) was obtained from Gist Brocades (King of Prussia, PA).

Chemicals

All chemicals were reagent-grade. Chloride and sulfate salts of zinc and aluminum were obtained from Fisher Scientific Co. (Fair Lawn, NJ), with the exception of zinc acetate (Sigma Chemical Co., St. Louis, MO); SAS (General Chemical Corp., Parsippany, NJ); SALP acidic (Rhône-Poulenc Basic Chemical Co., Shelton, CT), and sodium stearoyl-2-lactylate (SSL) (Grindsted Products, Industrial Airport, KS). All salt levels are reported in parts per million of metal ion based on flour at 14% mb.

Protein (N × 5.7), moisture, ash, and falling number of wheat flours were determined according to AACC Methods 46-11A, 44-15A, 08-11, and 56-81B, respectively (AACC 1995). Levels of components are reported on a 14.0% mb, except moisture, which is reported on a wet basis. A surface electrode (2001 pH probe, Sentron, Federal Way, WA) was used to measure pH of bread dough according to Miller et al (1994), and a chromameter (CR-310, Minolta Co. Ltd., Ramsey, NJ) was used to measure crumb color. Mixograms were run on a 10-g mixograph (AACC Method 54-40A), and farinograms were run on a 50-g Brabender Farinograph (AACC Method 54-21). Salts were added in solution to flour before mixing, except SALP and SAS, which were added as solids. Mixing curves were duplicated, and mean values of parameters from the curves were reported. Yeast activity was monitored by measuring gas production in triplicate doughs in a gasograph (12, DSI, Pullman, WA) (Rubenthaler et al 1980). Flour A (10 g, 14% mb) was slurried in water (15 mL, 30°C) containing sucrose (0.6 g), sodium chloride (0.15 g), yeast (0.2 g), and zinc ion (0.5–5.0 mg) as chloride, sulfate, and acetate salts. In other experiments, zinc was replaced by aluminum ion (0.5–5.0 mg), alone or with sodium ion, as sulfate and phosphate salts. Mixtures were fermented for 3 hr at 30°C, and yeast activity was reported in gasograph units.

Breadmaking

Most loaves were baked from commercial flour A (12.5% protein). A straight-dough, pup loaf procedure was used (AACC Method 10-10B) with the formula: flour (100 g, 14.0% mb), sucrose (6 g), nonfat dry milk (4 g), shortening (3 g), instant dry yeast (2 g), and malt (0.05 g), with or without potassium bromate or L-ascorbic acid. The bread formula was optimized for baking absorption, mixing time, and oxidant level by baking bread with each parameter at three levels, using a factorial design. Doughs were mixed to optimum in a 100-g pin mixer (TMCO-National Mfg. Co., Lincoln, NE), fermented 90 min, proofed 33 min at 30°C, and baked 24 min at 218°C.

All salts, except SALP and SAS, were added in solution to flour in the mixer. Salt solutions (2 mL) containing 50–500 ppm metal ion (flour basis) and solid salts were added after 90% of the mixing time had elapsed, and doughs were mixed to optimum. Baking absorption (optimum) for each flour was kept constant in all salt treatments.

Triplicate doughs were mixed and baked for each treatment. Loaf volumes were measured immediately after baking by rapeseed dis-

---

[1] Contribution 98-204 of the Kansas Agricultural Experiment Station, Manhattan, KS 66506.

[2] Graduate research assistant and professor, respectively, Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506.

[3] Corresponding author. E-mail: pas@wheat.ksu.edu

Publication no. C-1999-0415-06R.

placement, and loaves were evaluated subjectively for crumb grain after 1 hr on a scale of 0–6 (0, unsatisfactory; 1, questionable to unsatisfactory; 2, questionable; 3, questionable to satisfactory; 4, satisfactory; 5, excellent; and 6, outstanding). Excellent grade (5) is a bread crumb with extra-fine elongated cells in uniform layers with lacy, thin cell walls; questionable grade (2) is a crumb grain with somewhat open, mostly round and coarse cells irregularly sized and shaped with thick cell walls; and unsatisfactory grade (0) is a crumb grain with coarse, round cells extremely irregularly sized and shaped with thick cell walls. Outstanding grade (6) is a crumb grain graded as excellent as well as every other measured bread parameter, such as overall shape, appearance, loaf size, and crumb and crust color. Mean loaf volumes were reported, and the highest scores were reported for crumb grain. Each crumb grain most often agreed within ±1 of the assigned ranking.

Crumb Firmness and Sensory Analysis

Crumb firmness of bread at one, three, and seven days of storage was measured with a texture analyzer (TA-XT2, Stable Micro Systems, Haslemere, Surrey, England) according to Park et al (1997). A new loaf was used each day for measurement. Loaves were cut across the length in slices 25 mm thick, and two slices from near the center of each loaf were tested individually for firmness. Crumb was compressed to 10 mm (40%) at a crosshead speed of 1.7 mm/sec, and the force (N) reading was taken at 6.2 mm of compression or 25% of crumb thickness. Stress (N/m^2), defined as firmness, was calculated by dividing the compression force (N) by the contact area (1.018 × 10^{-3}/m^2) of the probe. The values of means for the three loaves are reported. Sensory evaluation of bread containing zinc (250 ppm) or aluminum (150 ppm) ions was done by triangular taste tests with 10 untrained panelists (ASTM 1968).

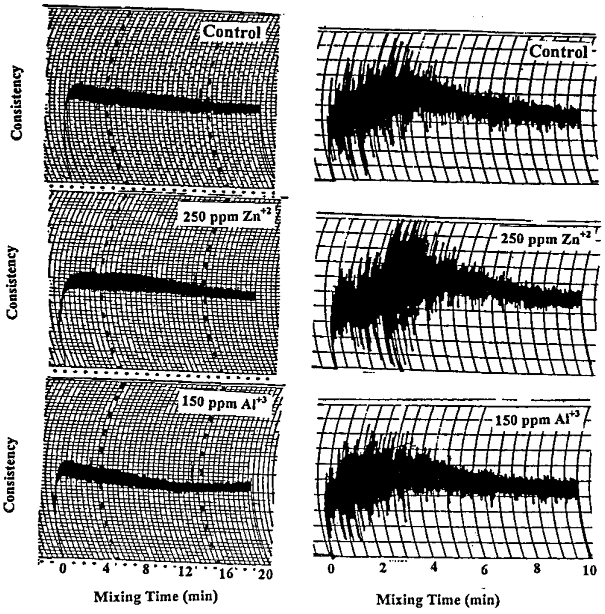

Fig. 1. Farinograms to 500 BU line and mixograms of flour-water doughs containing zinc and aluminum ions in the form of chloride and sulfate salts, respectively (levels given on flour basis, 14% mb). Doughs were mixed from commercial bread flour A (12.5% protein). Mixogram absorption was 60% for all doughs, and farinograph absorptions were 59.6, 60.2, and 59.6%, respectively, for negative control dough and doughs containing zinc chloride and aluminum sulfate.

Scanning Electron Microscopy of Bread Dough

Bread doughs were prepared with no oxidant and L-ascorbic acid (50 ppm) and zinc (250 ppm) and aluminum (150 ppm) ions as chloride and sulfate salts, respectively. Doughs immediately after mixing, and after first and second punch and proofing, were frozen directly in liquid nitrogen, cryofractured, and freeze-dried. Dry doughs were mounted on specimen stubs with silver paste and sputter-coated with gold. Samples were viewed and photographed with an Hitachi-H 300 (Ibaragi, Japan) scanning electron microscope.

Statistical Analysis

Analysis of variance with *t* test was performed, using a completely randomized design according to the general linear model procedure (Statistics Version 6.0, SAS Institute, Cary, NC). Means were compared by least significant difference at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Flours

Protein content of flours varied from 11.1 to 13.6%, and falling numbers varied from 350 to 528 sec; the falling numbers indicated flours had been milled from sound wheat (Table I). Flours pro-

TABLE II
Effects of Metal Salts on Gas Production in Yeast-Leavened Doughs[a,b]

	Metal Ion Level (ppm)[d]				
Salt[c]	**0**	**50**	**150**	**250**	**500**
$ZnCl_2$	69.9b	83.0a	81.8a	82.7a	80.0a
$ZnSO_4$	69.9a	71.0a	74.0a	74.0a	70.0a
$Zn(OAc)_2$	69.9c	76.2b	76.0b	76.2b	81.3a
$Al_2(SO_4)_3$	69.9b	71.0b	73.0b	75.0a	72.0b
SAS	69.9b	73.2b	75.7a	71.6b	73.0b
SALP	69.9c	81.7a	80.0a	77.3b	77.0b

[a] Average of three determinations. Values in a row followed by different letters significantly different at *P* = 0.05. GU = gasograph units.

[b] Yeast activity was determined by volume of gas (GU) released after 3 hr of dough (flour A) fermentation at 30°C.

[c] $(OAc)_2$ = acetate; SAS = sodium aluminum sulfate; SALP = sodium aluminum phosphate.

[d] Concentration on flour basis.

TABLE I
Wheat Flour Properties[a]

				Mixograph[b]				Bread	
Flour	**Protein (%)**	**Ash (%)**	**Falling No. (sec)**	**Absorption (%)**	**Mixing Time (min)**	**Peak Height (cm)**	**Tail Width (cm)**	**Loaf Volume[c] (cm^3)**	**Crumb Grain Score[d]**
Commercial									
A	12.5	0.55	421	60	3.3	6.5	1.4	885	3
B	11.1	0.51	350	58	4.0	5.7	1.2	828	3
Laboratory									
Comp 1	13.6	0.46	520	60	4.5	6.9	2.0	880	3
Comp 2	11.4	0.48	420	60	2.3	5.8	0.8	810	3
Comp 3	13.3	0.46	528	58	5.0	6.0	1.5	890	4

[a] Levels reported on 14% mb.

[b] Flours with elastic, mixing-tolerant dough show high values for peak height and tail width; tail width measured after 10 min of mixing.

[c] Loaf volume least significant difference = 15 cm^3. Breads made from doughs with optimum oxidant and water levels and mixing times.

[d] Subjective scores: 0 = unsatisfactory, 6 = outstanding.

duced varied mixograph data and breads that differed in loaf volume and crumb grain, indicating variable quality among flours. Mixograph mixing times varied from 2.25 to 5.0 min, and heights of mixing curves varied from 5.7 to 6.9 cm (Table I).

Metal Ions and Yeast Activity

Zinc and aluminum salts at 50–500 ppm metal ions in flour produced doughs that either maintained or increased (10%) gas production after 3 hr of fermentation (Table II). Zinc chloride and acetate enhanced gas production at all levels, whereas zinc sulfate did not. Among aluminum salts, SALP enhanced gas production at all levels, whereas aluminum sulfate and SAS maintained gas production. Finney et al (1949) reported accelerated yeast activity in dough containing 500 ppm zinc ion as chloride salt; Holmes and Hoseney (1987) reported similar improvement in gas production in doughs containing SALP and SAS at 50–500 ppm.

Adding zinc and aluminum salts at 50–500 ppm metal ions reduced initial dough pH from 5.9 to as low as 4.5. The optimum for baker's yeast activity is pH ≈ 5.5 (Pyler 1988). Holmes and Hoseney (1987) reported that yeast is relatively tolerant to changes in pH and that the rate of gas production remains at 80% of optimum or higher between pH 3.7 and 8.0. Thus, the slight reduction in dough pH caused by added zinc and aluminum salts did not appear to impair yeast activity in bread dough.

Mixograph and Farinograph Properties of Dough

The mixograph and farinograph properties of flour-water mixtures containing zinc and aluminum ions as chloride and sulfate salts, respectively, are given in Table III. Zinc ion at 50–500 ppm added as chloride salt to flour increased both farinograph absorption and dough development time but had little effect on stability and mixing tolerance. Saldamli et al (1996) reported similar changes in farinograms of doughs containing up to 1,340 ppm of zinc as acetate ion. Zinc ion at 250–500 ppm increased mixograph mix time by 23–31% and peak height by 6–10% and caused some dough weakening during overmixing, as indicated by a 20% decrease in tail width (Table III).

Aluminum sulfate at 50–500 ppm did not change farinograph absorption, except at 500 ppm, at which level absorption increased 1.5% (Table III). Aluminum sulfate at all levels, except 50 ppm aluminum ion, decreased development time and caused some weakening of dough, as indicated by reduced stability and increased mixing tolerance index values. Aluminum sulfate affected mixograms less than farinograms, perhaps because mixograph absorption was kept constant at 60% for flour A. Farinograph and mixograph curves for medium levels of zinc chloride and aluminum sulfate are shown in Fig. 1.

Zinc and Aluminum Ions in Breadmaking

Commercial flour A (12.5% protein) produced the highest bread loaf volume at 71% baking absorption, 4.0 min of mixing, and 20 ppm of potassium bromate or 50 ppm of L-ascorbic acid. Adding zinc salts in aqueous solution increased mixing time by as much as 50% (data not shown). However, prolonged mixing was eliminated by adding a salt solution after ≈90% of the mixing period was complete. The salt solution added during dough mixing represented 2 parts of a total 69–72 parts water per 100 parts flour A (14% mb).

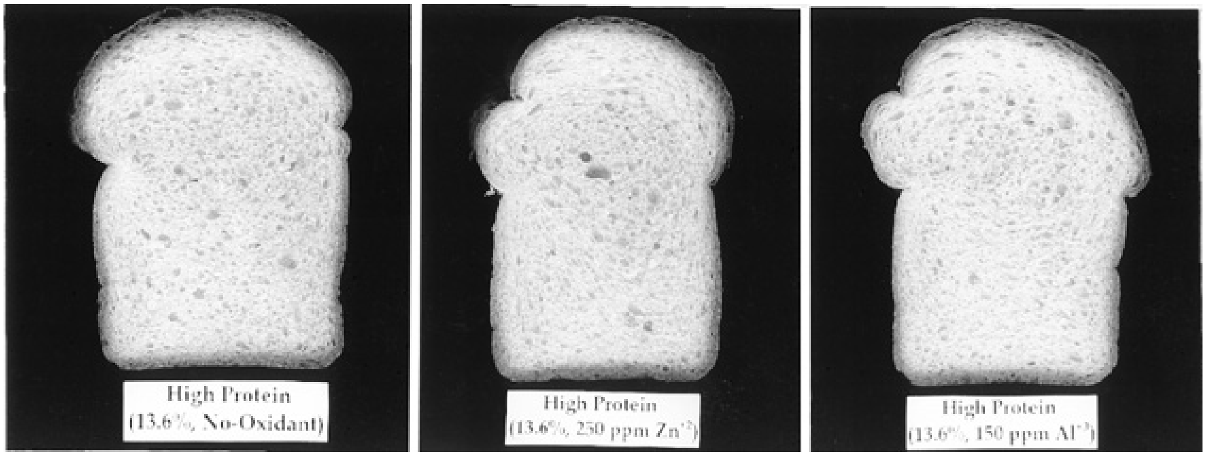

Fig. 2. Comparison of crumb appearance of breads made from a composite hard winter wheat flour (13.6% protein, 14% mb) containing from left to right: no oxidant, 250 ppm zinc ion (chloride salt), and 150 ppm aluminum ion (sulfate salt).

TABLE III
Effects of Zinc and Aluminum Ions on Mixing Properties of Flour-Water Doughs[a]

	Farinograph[b]				Mixograph[b,c]		
Ion Added (ppm)	Adsorption (%)	Development Time (min)	Stability (min)	MTI (min)	Mixing Time (min)	Peak Height (cm)	Tail Width (cm)
Negative control	59.6	2.2	11.5	24	3.3	6.5	1.4
Zn^{+2}							
50	59.7	2.4	10.5	18	3.5	6.5	1.3
150	60.1	2.7	11.4	15	3.8	6.8	1.1
250	60.2	2.8	13.4	4	4.0	6.9	1.1
500	61.1	2.7	12.0	20	4.3	7.2	1.1
Al^{+3}							
50	59.2	2.7	9.2	33	3.3	6.5	1.1
150	59.6	1.6	6.0	42	3.5	6.4	1.2
250	59.9	2.0	4.5	41	3.5	6.2	1.1
500	61.1	1.6	2.3	69	5.0	5.8	1.1

[a] Zinc and aluminum ions added as chloride and sulfate salts, respectively, to flour A.

[b] Average of two determinations. MTI = mixing tolerance index (negatively correlated with breakdown of dough during overmixing).

[c] Absorption constant at 60%.

Zinc ion at 50–500 ppm as zinc chloride did not cause noticeable differences in dough-handling properties. At 150 ppm, proof height (7.8 cm) of dough was not affected, but at 500 ppm, proof height increased to 8.1 cm (data not shown), confirming the increase in gas production determined using the gasograph. Adding 250 ppm zinc ion to flour A (Table IV) increased loaf volume from 848 cm^3 (control) to 875 cm^3, which was equal to 50 ppm of L-ascorbic acid (885 cm^3) and 20 ppm of potassium bromate (883 cm^3). At the same time, 250 ppm zinc ion improved crumb grain from questionable or unsatisfactory (1) to satisfactory (4) (Table IV). Finney et al (1992) reported no improvement in loaf volume and crumb grain at 2.5–24 ppm of zinc, which agreed with our data for low levels of added zinc. Zinc at 250 ppm produced bread with improved crumb grain when compared with optimum levels of potassium bromate or L-ascorbic acid. Identical improvements in crumb grain and similar increases in loaf volume were obtained for zinc acetate and sulfate (Table IV).

Aluminum sulfate at 50–150 ppm aluminum ion in flour A produced breads with improved loaf volume and crumb grain, but SAS and SALP did not improve volume or crumb grain (Table V). Mixing times of bread doughs containing 50–150 ppm aluminum ion increased by only 10%, yet salt was added in the last stages of mixing. A high level (500 ppm) of aluminum sulfate was detrimental to bread quality due to a weakening effect on gluten (Rao and Seib 1997). Aluminum sulfate does improve volume and grain of layer cakes made from untreated soft wheat flour (Johnson and Hoseney 1979).

Bake tests with commercial flour B and three composite flours (Comp 1, 2, and 3) containing zinc (250 ppm) and aluminum (150 ppm) added as chloride and sulfate salts, respectively, at optimal levels in the bread formula produced similar improvements in loaf volume and crumb grain score (Table VI). In Table VI, comparisons of loaf volumes for statistical differences were done in groups of four treatments for each flour.

The improvements in crumb grain due to zinc (250 ppm) and aluminum (150 ppm) ions are shown in Fig. 2. The crumb grain of bread made from dough containing no oxidant had a large central core with irregular cells, thick cell walls, and few elongated cells along the poorly visible slip plane. Addition of zinc or aluminum to the formula produced bread crumb with a small central core and numerous elongated cells, especially along the diagonal slip plane, which in Fig. 2 is visible from the left break of a loaf to the right bottom corner. Moreover, the crumb from bread with no oxidant reflected less light when compared with bread containing zinc or aluminum, which was especially noticeable for the loaf containing aluminum (Fig. 2). Based on the results, it appears that the opti-

TABLE IV
Loaf Volumes and Crumb Grain Scores of Breads Made from Commercial Flour A Containing Zinc Salts[a]

Metal Ion in Flour (ppm)[b]	Loaf Volume[c] (cm^3)	Crumb Grain Score[d]
Negative control, no oxidant	848b	1
Control, AsA (50 ppm)	885a	3
Control, $KBrO_3$ (20 ppm)	883a	2
Zinc chloride		
50	836b	1
150	863ab	2
250	875a	4
500	871a	4
Zinc acetate		
50	877a	1
150	892a	2
250	890a	4
500	903a	4
Zinc sulfate		
50	890a	1
150	887a	2
250	885a	4
500	880a	4

[a] All doughs mixed for 4 min with 71% baking absorption, fermented 90 min, and baked 24 min at 218°C.

[b] AsA = L-ascorbic acid; $KBrO_3$ = potassium bromate.

[c] Average of three observations. Values in a column followed by different letters significantly different at $P = 0.05$.

[d] Subjective scores: 1 = questionable to unsatisfactory, 4 = satisfactory.

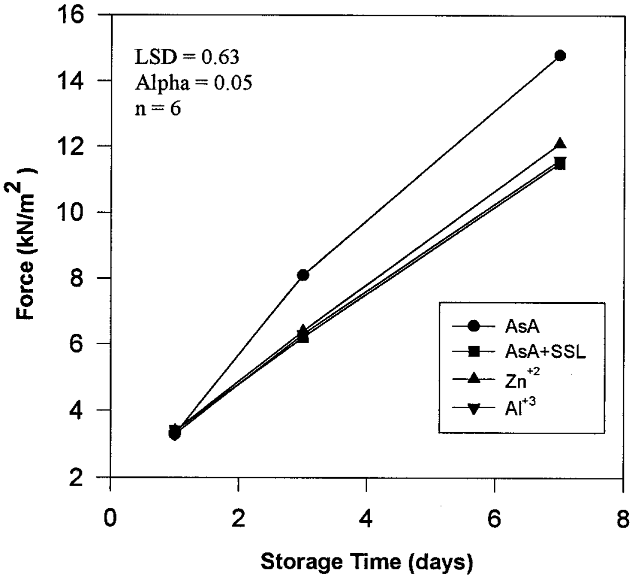

Fig. 3. Firmness of bread crumb containing 50 ppm of L-ascorbic acid (AsA), 50 ppm of L-ascorbic acid + 0.5% sodium stearoyl-2-lactylate (SSL), or 250 ppm zinc ion or 150 ppm aluminum ion (chloride or sulfate salt, respectively). Breads were made from commercial bread flour B (11.1% protein) at 69% absorption, and loaves were stored in polyolefin bags at 25°C.

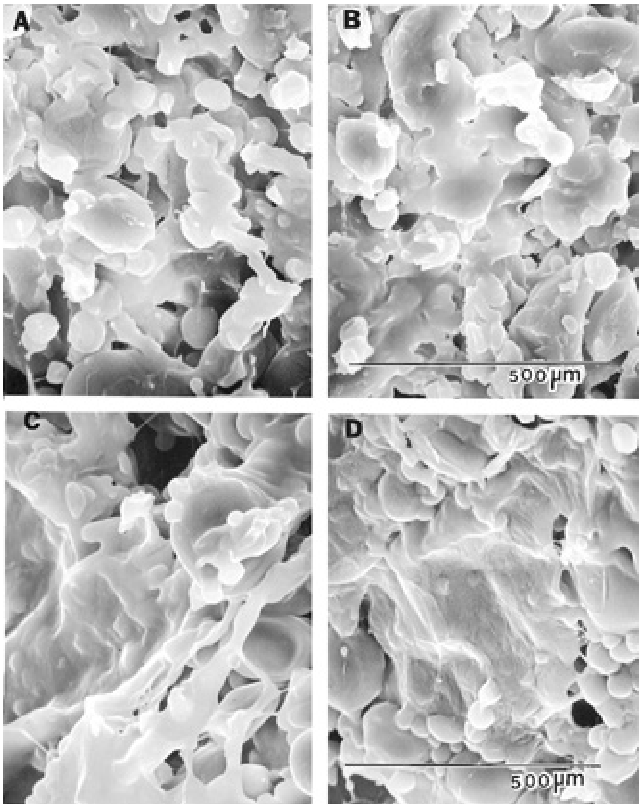

Fig. 4. Scanning electron micrographs (1,000×) of bread doughs after proofing, cryofracturing with liquid nitrogen, and freeze-drying. Doughs contained **A,** no oxidant; **B,** 50 ppm of L-ascorbic acid; **C,** 250 ppm zinc ion (chloride salt); or **D,** 150 ppm aluminum ion (sulfate salt).

mum zinc and aluminum levels for loaf volume and crumb grain improvement in white pan bread are 250 and 150 ppm, respectively.

Firming at 25°C was faster in control bread that contained L-ascorbic acid (50 ppm) than in bread containing either zinc ion (250 ppm), aluminum ion (150 ppm), or L-ascorbic acid (50 ppm) plus SSL (0.5%) (Fig. 3). During seven days of storage at 25°C, the firmness of bread containing zinc or aluminum was comparable to the firmness of bread containing SSL and significantly lower than control bread. The mechanism by which zinc and aluminum reduce bread firmness is unknown. Martin et al (1991) emphasized the importance of interactions (cross-links) between gluten and starch during staling. Zinc “softens or plastisizes” gluten protein (Rao and Seib 1997) and, therefore, may change the interaction between gluten and starch in bread and reduce firmness.

Zinc and Aluminum Combined with Potassium Bromate or L-Ascorbic Acid

Zinc ion (chloride salt) when added in combination with potassium bromate to bread dough improved both loaf volume and crumb grain, in a manner similar to zinc ion alone, suggesting that the combination is not detrimental (Table VII). De Stefanis et al (1988) reported no added zinc ion activity on bromate during breadmaking. On the other hand, combinations of zinc ion and L-ascorbic acid and combinations of aluminum ion (>250 ppm as sulfate salt) and L-ascorbic acid or potassium bromate caused decreased loaf volumes and inferior crumb grains (Table VII). The reason for reduction in loaf volume and crumb grain scores is unknown.

Scanning Electron Micrographs of Bread Dough

Immediately after mixing, wheat flour doughs containing no added zinc and aluminum ions or L-ascorbic acid showed a similar size distribution of gas cells at low scanning electron microscope magnification (50×) and similarities in coating of starch granules by gluten at high scanning electron microscope magnification (1,000×) (data not shown). However, at the proof stage and under high magnification, gluten network in doughs containing zinc or aluminum ions appeared to form a thin continuous film that coated many large wheat starch granules (Fig. 4C and D). A more discontinuous gluten film was observed in dough with no oxidant (Fig. 4A), whereas gluten film in dough with L-ascorbic acid was somewhat more continuous (Fig. 4B). Thus, scanning electron micrographs revealed that zinc and aluminum ions caused gluten to spread into a thin continuous film, which in turn may have allowed doughs to expand more uniformly. Uniform expansion may have prevented gas cells from

TABLE V
Loaf Volumes and Crumb Grain Scores of Breads Made from Commercial Flour A Containing Aluminum Salts[a]

Metal Ion in Flour (ppm)[b]	Loaf Volume[c] (cm^3)	Crumb Grain Score[d]
Negative control, no oxidant	848b	1
Control, AsA (50 ppm)	885a	3
Control, KBrO$_3$ (20 ppm)	883a	2
Aluminum sulfate		
50	872a	1
150	882a	4
250	850b	4
500	660c	1
SAS		
50	855b	1
150	853b	1
250	868b	3
500	863b	3
SALP		
50	843b	1
150	857b	1
250	850b	1
500	868b	1

[a] All doughs mixed from flour A for 4 min with 71% baking absorption, fermented 90 min and baked 24 min at 218°C.

[b] AsA = L-ascorbic acid; KBrO$_3$ = potassium bromate; SAS = sodium aluminum sulfate; SALP = sodium aluminum phosphate.

[c] Average of three observations. Values in a column followed by different letters significantly different at $P = 0.05$.

[d] Subjective scores: 1 = questionable to unsatisfactory, 4 = satisfactory.

TABLE VI
Loaf Volumes and Crumb Grain Scores of Breads Made from Flours Containing L-Ascorbic Acid (AsA) and Zinc and Aluminum Ions[a]

Flour[b]	Loaf Volume[c] (cm^3)	Crumb Grain Score[d]
B		
No oxidant	800b	1
AsA (50 ppm)	828a	3
Zn^{+2} (250 ppm)	840a	4
Al^{+3} (150 ppm)	820a	4
Comp 1		
No oxidant	805b	2
AsA (25 ppm)	880a	3
Zn^{+2} (250 ppm)	880a	4
Al^{+3} (150 ppm)	880a	4
Comp 2		
No oxidant	780b	1
AsA (100 ppm)	810a	3
Zn^{+2} (250 ppm)	810a	3
Al^{+3} (150 ppm)	805a	3
Comp 3		
No oxidant	810c	2
AsA (50 ppm)	890a	4
Zn^{+2} (250 ppm)	888a	4
Al^{+3} (150 ppm)	850b	4

[a] Zinc and aluminum ions added as chloride and sulfate salts, respectively.

[b] Baking absorption of flours: 69% for flour B; 72, 71, and 69% for Comp 1, 2, and 3, respectively.

[c] Average of three observations. Values in each group (four breads) followed by different letters significantly different at $P = 0.05$.

[d] Subjective scores: 1 = questionable to unsatisfactory, 4 = satisfactory.

TABLE VII
Effect of Zinc or Aluminum Ions[a] Combined with Potassium Bromate (KBrO$_3$ at 20 ppm) or L-Ascorbic Acid (AsA at 50 ppm) on Loaf Volume and Crumb Grain of Bread Made from Commercial Flour A

Metal Ion Treatment (ppm)	Loaf Volume[b] (cm^3)	Crumb Grain Score[c]
AsA	885b	3
Zn^{+2} ion		
50	836d	1
150	863bc	2
250	875b	4
500	871b	4
Zn^{+2} + KBrO$_3$		
50	910a	2
150	910a	3
250	897a	4
500	882b	4
Zn^{+2} + AsA		
50	858c	3
150	818e	2
250	765g	1
500	637h	1
Al^{+3} + KBrO$_3$		
50	908a	3
150	880b	3
250	800f	1
500	640h	1
Al^{+3} + AsA		
50	887b	3
150	845d	2
250	765g	1
500	600i	1

[a] Added as zinc chloride and aluminum sulfate salts.

[b] Average of three observations. Values in a column followed by different letters significantly different at $P = 0.05$.

[c] Subjective scores: 1 = questionable to unsatisfactory, 4 = satisfactory.

coalescing and produced bread with an improved crumb appearance. Gan et al (1990, 1995) emphasized the involvement of interfacial films at the gas-liquid interface inside dough. Surface active materials such as endogenous flour polar lipids, proteins, and pentosans that dissolve in the dough aqueous phase may contribute positively to gas retention by stabilizing the film, allowing it to expand to a larger surface area without rupturing.

Nutritional Implications of Adding Zinc to Bread

The National Research Council (1989) recommends a daily allowance of 12 and 15 mg of zinc for adult women and men, respectively. There is no recommended dietary allowance for aluminum ion. Both zinc and aluminum ions are generally recognized as safe (FDA 1995).

Assuming there is 300 g of flour in a 1-lb loaf of bread containing 250 ppm zinc ion (flour basis), there would be 75 mg of zinc per loaf or 3.75 mg in one of 20 slices. Thus, four slices would contain 15 mg (at least 100% RDA) of zinc. Currently there is interest in adding zinc oxide or sulfate to flour at ≈30 ppm of zinc, which is approximately one-tenth the level at which zinc ion improved breadmaking.

The estimated intake of nutritional elements found in the Total Diet Study conducted over a nine-year period (1982–1991) by the U.S. Food and Drug Administration (FDA) revealed that zinc intake was 20–30% below the RDA standards set by the National Academy of Sciences (NAS) for five age-sex groups (Pennington and Schoen 1996). Recent studies conducted at Tuft's Human Nutrition Research Center on Aging revealed that in postmenopausal women and people of both sexes who are at least 65 years of age and consume 1,500 mg of calcium daily, calcium interferes with zinc absorption and balance. It was recommended that people who consume 1,500 mg of calcium daily also should take 10 mg of supplemental zinc daily (Wood 1997). There appears to be a need to consume foods rich in zinc, and zinc-supplemented bread could be one option. On the other hand, excessive intake (10–30 times the RDA) of zinc for several weeks reportedly results in hypocupremia, impairment of immune responses, and decline in high-density lipoprotein cholesterol levels (Hooper et al 1980, Chandra 1984, Fischer et al 1984)

Sensory analysis results by 10 untrained panelists indicated that the presence of zinc or aluminum at 250 and 150 ppm, respectively, in bread did not impart an undesirable taste to the final product (data not given). Our results agree with those of Saldamli et al (1996) who reported no adverse taste in breads supplemented with up to 1,340 ppm of zinc in the form of zinc acetate.

CONCLUSIONS

White pan bread with improved loaf volume and crumb grain can be produced by incorporating 250 or 150 ppm zinc and aluminum ions (flour basis), respectively, in bread dough. Zinc or aluminum ion in bread also reduces the firming rate of the crumb.

ACKNOWLEDGMENTS

We thank A. Reichuber, Jr., Cargill Flour Milling Division (Wichita, KS) and P. McCluskey, senior scientist, Wheat Quality Testing Laboratory (Kansas State University, Manhattan, KS) for providing flour samples; R. C. Hoseney, retired professor (KSU), for helpful discussions; and L. H. Willard, Veterinary Clinical Sciences (KSU), for technical support in microscopy.

LITERATURE CITED

American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. Method 08-11, final approval October 1976, reviewed October 1981 and October 1994; Method 10-10B, approved November 1995; Method 44-15A, approved October 1975, revised October 1981 and October 1994; Method 46-11A, approved October 1976, revised October 1982 and September 1985, reviewed October 1994; Method 54-21, final approval November 1995; Method 54-40A, final approval November 1995; Method 56-81B, approved November 1972, revised October 1982, October 1988, and September 1992, reviewed October 1994 The Association: St. Paul, MN.

ASTM. 1968. American Society for Testing and Materials Manual on Sensory Testing Methods. Special Technical Publication 434, 24067. The Society: Philadelphia.

Chandra, R. K. 1984. Excessive intake of zinc impairs immune responses. J. Am. Med. Assoc. 252:1443-1446.

De Stefanis, V. A., Ranum, P. M., and Erickson, R. W. 1988. The effect of metal ions on bromate oxidation during breadmaking. Cereal Chem. 65: 257-261.

Finney, K. F., Bruinsma, B. L., and Natasuaki, O. 1992. Copper (II) vs. zinc inorganic salts as oxidizers in breadmaking. Cereal Chem. 69:347-348.

Finney, K. F., McCammon, J. F., and Schrenk, W. G. 1949. Effect of varying concentrations of certain metals and their salts on gas production and loaf volume. Cereal Chem. 26:140-148.

Fischer, P. W. F., Giroux, A., and L'Abbe, M. R. 1984. Effect of zinc supplementation on copper status in adult man. Am. J. Clin. Nutr. 40:743-746.

FDA. 1995. Code of Federal Regulations: Part 182-Substances Generally Recognized as Safe. Food and Drug Administration: Washington, DC.

Gan, Z., Angold, R. E., Williams, M. R., Ellis, P. R., Vaughan, J. G., and Galliard, T. 1990. The microstructure and gas retention of bread dough. J. Cereal Sci. 12:15-24.

Gan, Z., Ellis, P. R., and Schofield, J. D. 1995. Mini review: Gas cell stabilization and gas retention in wheat bread dough. J. Cereal Sci. 21:215-230.

Holmes, J. T., and Hoseney, R. C. 1987. Chemical leavening: Effect of pH and certain ions on breadmaking properties. Cereal Chem. 64:343-348.

Hooper, P. L., Visconti, L., Garry, P. J., and Johnson, G. E. 1980. Zinc lowers high-density lipoprotein cholesterol levels. J. Am. Med. Assoc. 244:1960-1961.

Hoseney, R. C. 1984. Gas retention in bread dough during baking. Cereal Foods World 29:305-308.

Johnson, A. C., and Hoseney, R. C. 1979. Chlorine treatment of cake flour. II. Effect of certain ingredients in the cake formula. Cereal Chem. 56: 336-338.

Junge, R. C., Hoseney, R. C., and Varriano-Marston, E. 1981. Effect of surfactants on air incorporation in dough and the crumb grain of bread. Cereal Chem. 58:338-342.

Kamman, P. W. 1970. Factors affecting the grain and texture of white bread. Baker's Dig. 44(2):34-38.

Martin, M. L., Zeleznak, K. J., and Hoseney, R. C. 1991. A mechanism of bread firming. I. Role of starch swelling. Cereal Chem. 68:498-503.

Miller, R. A., Graf, E., and Hoseney, R. C. 1994. Leavened dough pH determination by an improved method. J. Food Sci. 59:1086-1087, 1090.

NRC. 1989. Recommended dietary allowances. Subcommittee on the 10th edition of the RDAs. National Research Council/National Academy of Sciences: Washington, DC.

Pennington, J. A. T., and Schoen, S. A. 1996. Total diet study: Estimated dietary intake of nutritional elements 1982–1991. Int. J. Vit. Res. 66:350-362.

Pyler, E. J. 1988. Dough Fermentation. Pages 625-656 in: Baking Science and Technology, vol. 2. E. J. Pyler, ed. Sosland Publishing Company: Merriam, KS.

Ranum, P. 1992. Potassium bromate in bread baking. Cereal Foods World 37:253-258.

Rao, V. K., and Seib, P. A. 1997. Two metal ions improve brightness in wheat-dough products and affect aqueous dispersion of gluten. Cereal Chem. 74:318-325.

Rubenthaler, G. L., Finney, P. L., Demaray, D. E., and Finney, K. F. 1980. Gasograph: Design, construction, and reproducibility of a sensitive 12-channel gas recording instrument. Cereal Chem. 57:212-216.

Saldamli, I., Koksel, H., Ozboy, O., Ozalp, I., and Kilic, I. 1996. Zinc-supplemented bread and its utilization in zinc deficiency. Cereal Chem. 73:424-427.

Wood, R. 1997. Calcium takers may need more zinc. Tufts Univ. Health & Nutr. Lett. 15(7):6.

[Received October 26, 1998. Accepted January 8, 1999.]