Effect of Nonchaotropic Salts on Flour Bread-Making Properties[1]

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ABSTRACT

Cereal Chem. 69(4):366–371

Mixograph characteristics of wheat flour doughs were found to be affected by the addition of neutral salts. Changes in mixograph properties such as time to peak, peak height, or curve width were dependent on the specific ions present and their concentration. In bake tests, certain salts from both the precipitating and the solubilizing portions of the lyotropic series increased loaf volume relative to bread without salt. This was not true for all salts, possibly because of a negative action on gas production of yeast. The extent of the improvement and the optimum usage level varied for each salt. Nonchaotropic salts increased the dough strength of flours of varying quality. The order of increasing flour strength followed the order of the original strength of the flours at the same level of salt. Na_2SO_4 had a more pronounced effect than did NaCl. Compared with NaCl, Na_2SO_4 greatly improved the rheological properties and the gas-retaining ability, as well as the loaf volume and crumb grain, of the poor-quality flour (presumably by increasing hydrophobic interactions between gluten proteins). However, the same level of Na_2SO_4 made the good-quality flour dough too elastic for breadmaking. The effect of nonchaotropic salt supported the hypotheses that the surface of the gluten proteins from the poor-quality flour was less hydrophobic than that from the good-quality flour, and that the hydrophobic interactions between proteins are important to bread quality. However, this study also demonstrated that the improvement in baking quality of poor-quality flour by salt was limited, which indicates that other factors besides hydrophobic interaction affect the baking properties of flours.

Gluten is viscoelastic when hydrated and is composed of two main groups of proteins: gliadin and glutenin. Gliadin is single-chained, has little or no resistance to extension, and imparts cohesive properties to gluten. Glutenin is multichained by disulfide bond linkages and physically is resilient. The glutenin gives elasticity to gluten. However, how these two sets of proteins interact with each other and with themselves to form gluten is still largely unknown (Hoseney 1986).

The amino acid composition shows that gluten proteins have 35% hydrophobic amino acids (14% proline), 35% hydrophilic amino acid, and 7% charged amino acids (McDonald and Gilles 1967). That composition would favor hydrophobic interactions between gluten proteins. Kinsella (1982) has suggested that above 28% hydrophobic amino acid, the apolar residues will not be accommodated in the hydrophobic core. Thus, surface hydrophobicity increases, which promotes protein aggregation because of hydrophobic interactions (Fisher 1964, Melander and Horvath 1977). Therefore, it is believed that hydrophobic interactions between gluten proteins play an important role in stabilizing gluten structure and in the rheological and baking properties of flours (Bernardin and Kasarda 1973).

Differences in hydrophobicity between poor- and good-quality flour proteins were observed by Chung and Pomeranz (1979). They used Phenyl-Sepharose CL-4B as a hydrophobic gel and showed that glutenin from a poor-baking wheat cultivar was less hydrophobic than glutenin from a good-baking cultivar. In contrast, gliadin from a poor cultivar was more hydrophobic than that from a good cultivar.

The hydrophobic interactions between gluten proteins could be changed by addition of neutral salts (Bennett and Ewart 1965; Preston 1981; Danno and Hoseney 1982; Salovaara 1982; Kinsella and Hale 1984; Preston 1984, 1989). Preston (1981) found that at a low concentration of sodium salts ($0.05M$) the extractability of protein decreased and the aggregation increased, independent of anion type. The strong salting-out tendencies might be related to electrostatic shielding of ionic amino acids on the protein surface. At high salt concentration ($>0.5M$), the extractability and aggregation were highly dependent on anion type and followed the lyotropic anion series (Hofmeister series).

An increase of salt concentration generally increases the ordering of water structure. However, this ordering is highly dependent on anion type, with nonchaotropic ions strongly promoting ordering of water structure and chaotropic anion having only small ordering effects. The increase in ordering of water structure results in the exposure of apolar groups on protein to solvent, which allows proteins to interact with each other through hydrophobic interactions (Von Hippel and Schleich 1969, Melander and Horvath 1977).

Huebner (1970) compared the precipitation behaviors of different glutenins from 11 wheat cultivars varying in baking quality and showed that gluten quality was related to the sensitivity of its glutenins to changes in ionic strength. The glutenins from cultivars of good baking quality yielded steeper precipitation curves than those from poor-quality cultivars. Arakawa and Yonezawa (1975) also investigated the aggregation behaviors of glutens from four flours with various baking qualities by recording the time course of turbidity of the gluten suspension. They found that the better baking quality a flour had, the more gluten protein aggregated, and the aggregation behavior of gluten was determined mainly by the nature of its glutenin.

The effect of salts on the baking properties of good-quality flour has been studied. Preston (1984) reported that the addition of sodium salts ($0.05–0.10M$) increased dough strength. At a higher salt concentration ($0.5–1.0M$), chaotropic anions reduced dough strength and increased farinograph water absorption, whereas nonchaotropic anions increased dough strength and had little effect on absorption. Similar results were obtained by Kinsella and Hale (1984) and Smith and Mullen (1965). Danno and Hoseney (1982) studied the effect of sodium chloride (NaCl) and sodium dodecyl sulfate (SDS) on mixograph properties. NaCl (2–5%) and SDS (0.5–1.0%) increased the width and height of the mixogram curve and increased mixing time. The effect of overmixing could be reversed by the addition of NaCl or SDS to doughs overmixed in the presence of potassium iodate, ferulic acid, or *N*-ethylmaleimide.

Salts generally increase dough strength, but they do not necessarily improve loaf volume (Holmes and Hoseney 1987a). This might be explained by the facts that the strong flour dough has sufficient strength to make a good loaf and that the addition of salt makes the dough too strong for breadmaking. However, there is little or no literature on the effects of salt on the dough properties of flours of poor baking quality. The purpose of this study was to examine and to better understand the effects of salts on dough and the resultant bread. A second major part of the study was to investigate whether nonchaotropic salts can improve the dough rheological properties as well as the baking quality of a poor-quality flour.

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MATERIALS AND METHODS

Materials

Two commercial bread flours labeled A and B were provided by Ross Mills, Wichita, KS. Three hard red winter flours, KS 501097, KS 644, and CI 12995, were used as flours varying widely in breadmaking quality. KS 501097 flour is a poor-quality bread flour, KS 644 belongs in the medium-quality range, and CI 12995 flour is a good-quality bread flour. The protein, ash, and baking results for the flours are given in Table I.

The shortening was partially hydrogenated and contained mono- and diglycerides (Crisco, Procter and Gamble, Cincinnati, OH). The yeast used was Fermipan instant dry yeast (Gist-Brocades, Charlotte, NC). Sodium iodide, sodium chloride, sodium phosphate monobasic, sodium sulfate, sodium citrate, and monocalcium phosphate were all reagent grade.

Gas Production

The gasograph (DSI gasograph, model 12, Pullman, WA) was used to determine gas production. Samples were prepared by the method described by Rubenthaler et al (1980). Duplicate determinations were made. Gas production in gasograph units was determined over 4 hr of fermentation.

Mixograph and Baking

Mixograms were produced by AACC method 54-40A (AACC 1983). Dry salts were directly added to flour before mixing. In certain studies a 10-g breadmaking procedure was used (Shogren and Finney 1984).

The straight-dough bake test procedure followed was AACC method 10-10B (AACC 1983). Nonfat dry milk (NFDM; 4.0%) (Gallaway West, Fond du Lac, WI), and optimum $KBrO_3$ were added to the formula for all of the baking results, except for the baking test for flours of different baking quality. The doughs were mixed to optimum (minimum mobility) in a National special 100-g pin mixer (TMCO-National Mfg. Co., Lincoln, NE). The dough was fermented in a proof cabinet (TMCO-National Mfg. Co.) at 30°C and 90–95% relative humidity for 180 min. During the fermentation, the dough was sheeted at a gap of 0.048 cm after 105 and 155 min. At the end of the fermentation, the dough was sheeted at a gap of 0.803 cm and then molded in a drum molder (Thomson Co., Beltsville, NJ). The dough piece was panned (dimensions: top, 77 × 142 mm; bottom, 62 × 126 mm; depth, 57 mm) and then proofed at 30°C and 90–95% relative humidity for 55 min. The proofed dough was baked at 218°C for 24 min. Immediately on removal from the 12 1-lb electric reel oven (TMCO-National Mfg. Co.), the loaf was weighed and the volume was taken by rapeseed displacement.

TABLE I
Analysis of Flours[a]

Flour	Protein (%)	Ash (%)	Loaf Volume (cm³)
Commercial bread flours			
A	12.0	0.48	884
B	12.3	0.49	987
Quality series[b]			
CI 12995	12.7	0.48	800
KS 644	10.9	0.47	600
KS 501097	13.9	0.48	470

[a] Values reported on a 14% moisture basis.
[b] Flours in this series were baked with no milk and no oxidant. They are listed in descending order (good, intermediate, poor) of breadmaking quality.

TABLE II
Effect of Sodium Iodide on Mixograph Time to Peak and Peak Height[a]

Treatment[b]	Time to Peak (min)	Peak Height (cm)
No salt (control)	3.48 b	6.6 c
Salt added, *M*		
0.05	4.23 a	7.0 bc
0.10	4.20 a	7.2 b
0.30	3.55 b	7.2 b
0.40	3.35 bc	7.2 b
0.50	2.93 cd	6.8 bc
1.00	2.50 d	5.9 d
4.00	1.23 e	9.0 a

[a] Values within a column followed by different letters indicate statistically significant differences at the 5% level. Two replications for each treatment.
[b] 59% water absorption for all variations except 4.00*M* at 140%.

Statistical Analysis

Analysis of variance with *t* tests (least significant difference) using the Statistical Analysis System (SAS Institute, Cary, NC) was used for the evaluation of the data.

RESULTS AND DISCUSSION

Effect of Sodium Salts

Various sodium salts were added at equal amounts (percentages based on flour weight). Sodium sulfate produced a curve with the longest mix time, followed closely by citrate, then by phosphate (monobasic) and chloride, which were similar. When converted to an equivalent mole basis, mixing time increased in the following order: chloride, phosphate, sulfate, citrate.

Sodium iodide at low levels (0.05 to 0.10*M*) increased mix time and curve height (Table II). However, as concentration was increased, both of those attributes maximized and then began to decrease. This coincides with the salting-out effect of the protein at low chaotropic salt concentrations followed by salting-in at higher concentrations as reported by Preston (1981). At 4*M* sodium iodide, the absorption was increased to 140%. The time to peak was reduced to 1 min, and the peak height increased to 9.0 cm. The curve was narrow throughout.

Bake tests with various sodium salts showed that each salt at its optimum level gave an improved loaf volume (Tables II and III, Fig. 1). The level producing the largest loaf volume for each salt was not the same. The optimum level for sodium chloride has been shown to be 1.5% (Finney 1984). In this study, the optimum level for sodium sulfate was found to be 0.75% (Fig. 1), and the optimum for sodium phosphate monobasic was broad and about 1.0% (Fig. 1). Also, the maximum loaf volume obtained for each salt varied. At the optimum levels, sodium chloride produced the largest volume. These results are in good agreement with those reported by Holmes and Hoseney (1987a).

To determine the effect on loaf volume of a salt from the solubilizing end of the lyotropic series, sodium iodide was evaluated in a bread formulation. This salt was baked with commercial flours A and B. The results from the first test (Table

TABLE III
Effect of Sodium Iodide on Loaf Volume

Treatment	Loaf Volume,[a] cm³ Flour A	 Flour B
Control		
1.5% NaCl	884[b] b	987[e] a
No salt	848[c] b	953[c] b
NaI, %		
0.25	. . .	955[c] b
0.50	915[d] a	. . .
1.00	902[d] a	963[c] b
1.50	910[d] a	980[d] a
2.00	. . .	960[c] b

[a] Values within a column followed by different letters indicate statistically significant differences at the 5% level.
[b] Average of five observations.
[c] Average of three observations.
[d] Average of two observations.
[e] Average of six observations.

III) with flour A indicated that sodium iodide produced bread with a slightly larger volume than that of sodium chloride when both salts were used at their optimum levels. The optimum for sodium iodide also was broader than that for sodium chloride. The volume was essentially constant from 0.5 to 1.5%. When baked without NFDM, the optimum level of sodium iodide decreased to 0–0.5% salt. This is similar to the optimum of sodium chloride with no NFDM (Holmes and Hoseney 1987b). The test with flour B did not show sodium iodide to have as great of an improving effect nor to have as broad of an optimum (Table III) as previously found. A more definite optimum was found at 1.5% sodium iodide. At that optimum, the loaf volume was similar to that found with sodium chloride rather than with the larger volume found in the previous test. The fact that different flours were used in each test may account for the discrepancy between tests. Protein quality may have varied between the flours. Salts may cause different effects on flours of different qualities (Gortner et al 1929).

The internal characteristics of the loaves baked with sodium iodide appeared overoxidized. This was shown by thick cell walls and a slightly darker core in the center of the crumb. The appearance of overoxidation became more evident as the level of sodium iodide was increased. Externally, the appearance of overoxidation was indicated by less pan flow, i.e., rounded edges of the loaf and a more apparent seam. De Stefanis et al (1988) showed that certain metallic ions interacted with oxidants (potassium bromate) or themselves caused oxidative effects in bread. The sodium ion was not found to be one of these cations. Possibly, anions such as iodide may interact with the oxidant present in a manner similar to cations as shown by De Stefanis et al (1988).

Effects of Other Cation Salts

Salts containing cations other than sodium were evaluated for their effect on mixograms, in bake tests, and on gas production. This was to determine if various cations affected the baking properties of flours differently.

The mixograph results (Table IV) showed that calcium chloride did not significantly affect mix time. Sodium chloride had little effect at low levels (0.5%) but caused a significant increase in mixing time at higher levels (1.5 and 4%). Lithium chloride had a lesser effect on mixing time and potassium chloride a greater effect than did sodium chloride when used at comparable levels (data not shown).

Bake tests with calcium chloride and lithium chloride (Fig. 2) (replacing 1.5% sodium chloride) did not show an optimum

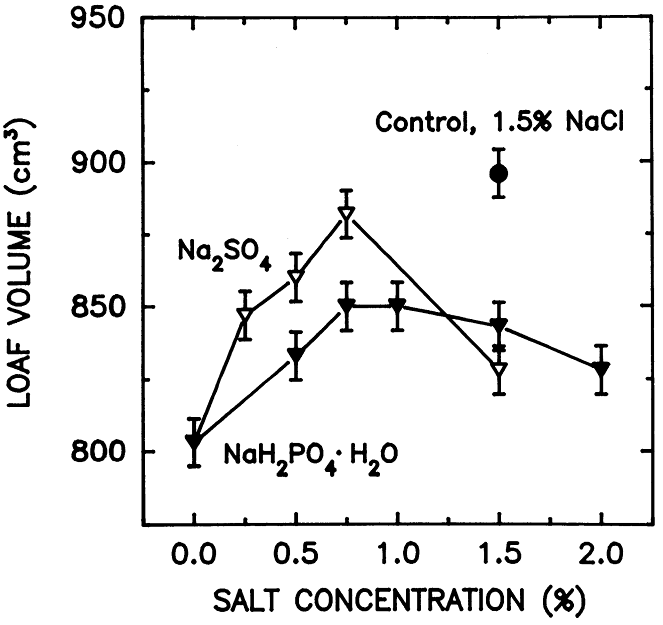

Fig. 1. Effect of various concentrations of Na_2SO_4 and $NaH_2PO_4 \cdot H_2O$ on loaf volume of bread. Error bars have a least significant difference value of 1.

TABLE IV
Effect of Calcium Chloride and Sodium Chloride on Mix Time and Peak Height[a]

Salt	Mix Time (min)	Peak Height (cm)
Control (no salt)	3.50 c–e	6.7 d
Sodium chloride, %		
0.5	3.33 c	5.8 c
1.5	4.25 b	6.0 b
4.0	5.60 a	6.1 a
Calcium chloride, %		
0.5	3.28 de	7.0 c
1.5	3.28 de	7.0 c
4.0	3.15 e	6.6 d
8.0	3.60 cd	7.2 bc

[a] Values within a column followed by different letters indicate statistically significant differences at the 5% level; average of at least two observations.

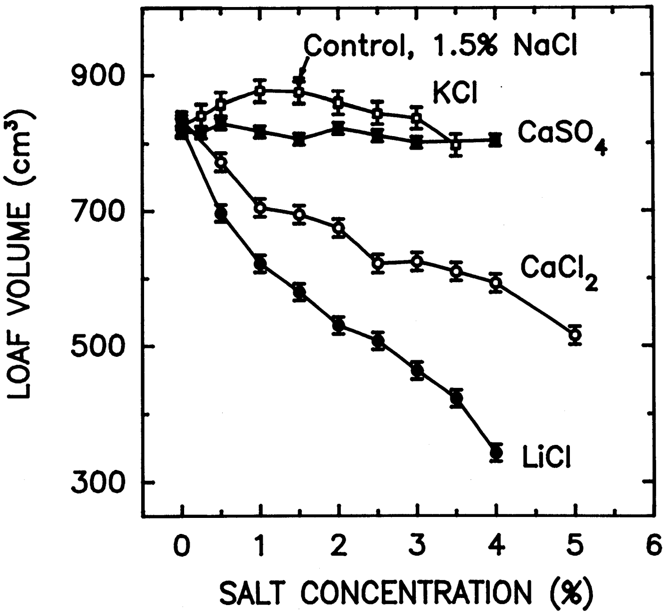

Fig. 2. Effect of various concentrations of KCl, $CaSO_4$, $CaCl_2$, and LiCl on the loaf volume of bread. Error bars have a least significant difference value of 1.

TABLE V
Effect of Potassium Chloride on Loaf Volume[a]

Treatment	Loaf Volume With NFDM[b] (cm^3)	Loaf Volume Without NFDM (cm^3)
Control	869 ab	908 ab
No Salt	827 cd	907 ab
Potassium chloride, %		
0.25	842 bc	882 b
0.50	858 a–c	923 a
1.00	877 a	928 a
1.50	875 a	937 a
2.00	860 ab	915 ab
2.50	845 a–c	845 c
3.00	838 bc	845 c
3.50	798 d	. . .
4.00	. . .	820 c

[a] Values within a column followed by different letters indicate statistically significant differences at the 5% level. Average of at least two observations.
[b] Nonfat dried milk.

at any levels tested. Lower loaf volumes were produced at all levels. Potassium chloride did show an optimum level (1.0–1.5%) both with and without NFDM (Table V). This is in contrast to sodium chloride, which showed an optimum without NFDM at 0.0–0.5%. The optimum level of potassium chloride produced bread volume that was similar to that of the optimum level of sodium chloride when NFDM was present and that was slightly larger when NFDM was not present. Calcium sulfate (0.0–4.0%), which is relatively insoluble, did not have any effect on loaf volume (Fig. 2).

TABLE VI
Effect of Potassium, Sodium, Calcium, and Lithium Chlorides on Yeast Gas Production

Treatment[a]	Weight (g)	Gas Production[b] (GU)
No salt	0.000	67.8 a
Potassium chloride	0.191	65.5 ab
Sodium chloride	0.150	61.8 b
Calcium chloride		
Equivalent anion	0.142	55.0 c
Equivalent cation	0.285	52.3 cd
Lithium chloride	0.109	48.0 d

[a] Salts at same ionic level as 1.5% sodium chloride, except calcium chloride, which was used at either the same anionic or cationic level, as indicated.

[b] Values followed by different letters indicate statistically significant differences at 5% level.

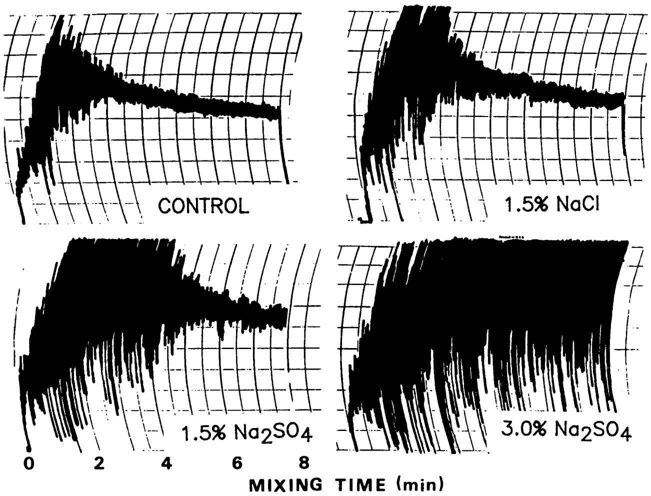

Fig. 3. Effect of salts on mixograms of KS 501097 (poor quality) flour, 65% absorption.

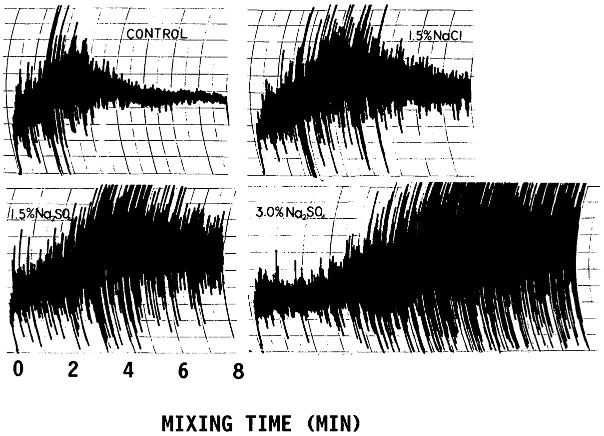

Fig. 4. Effect of salts on the mixograms of KS 644 (intermediate quality) flour, 60% absorption.

Effect of Various Salts on Gas Production

The deleterious effects of lithium chloride on loaf volume were suspected to be an effect on gas production. Therefore, various salts were examined for their effects on gas production. Certain salts, particularly lithium chloride and calcium chloride, apparently had a toxic effect on yeast (Table VI). This would, at least in part, explain their negative effects on loaf volume.

Effect of Salts on Flours of Different Baking Quality

As suggested above, flours of different baking quality may interact with salts differently. Therefore, three pure cultivar flours of widely different baking quality were used to study the effect of two nonchaotropic salts, NaCl and Na_2SO_4. The latter is much less chaotropic than the former.

Figures 3–5 show mixograms of KS 501097, KS 644, and CI 12995 flours with no salt, with the addition of 1.5% NaCl, or with 0.75, 1.5, or 3% Na_2SO_4. Without any salt, KS 501097 flour gave a typically weak flour mixogram, KS 644 flour a relatively weak mixogram, and CI 12995 flour a relatively strong mixogram. With addition of either NaCl or Na_2SO_4, the mixing time of all flours increased. The effect of 1.5% Na_2SO_4 was much greater than that of 1.5% NaCl.

The mixograph mixing time and peak height of all three doughs increased with increased Na_2SO_4. It took 9.5 min to develop CI 12995 dough in the presence of 1.5% Na_2SO_4 compared with 5.5 min for dough with no salt. With the addition of 3.0% Na_2SO_4, it took 8 min to develop KS 644 dough and only 4 min to develop KS 501097 dough. Compared with no salt, the KS 501097 dough with 3.0% Na_2SO_4 gave a strong mixogram without breaking down by the end of 8 min of mixing. Therefore, the two non-

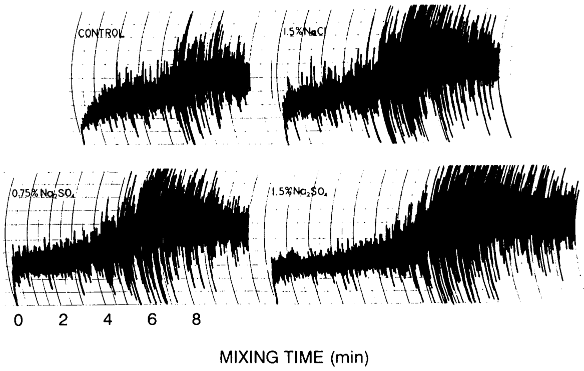

Fig. 5. Effect of salts on the mixograms of CI 12995 (good quality) flour, 61% absorption.

TABLE VII
Effect of Salts on Dough Baking Properties

Treatment	H_2O Absorbency (%)	Mixing Time (min)	Dough Handling[a]	Proof Height (mm)	Oven Spring (mm)	Loaf Volume[b] (cm^3)
KS 501097						
Control	67	1.33	1	36.0	−3.5	37.7 ± 1.9
Na_2SO_4, %						
0.75	67	1.83	2	41.3	−1.0	54.3 ± 1.0
1.5	68	2.00	3	42.7	1.0	61.8 ± 1.5
2.25	71	2.75	3	42.7	2.0	61.8 ± 1.6
3.0	73	3.33	4	42.3	4.0	64.3 ± 0.9
4.5	75	6.00	4	39.0	3.0	52.1 ± 1.3
NaCl, 1.5%	67	1.50	1	40.0	−1.0	47.0 ± 0.5
CI 12995						
NaCl, 1.5%	65	5.00	5	42.0	8.5	75.1 ± 0.9

[a] Dough properties were subjectively judged by dough handling and scored 1 to 5, where 1 was described as a very poor-quality bread flour dough with poor handling properties and slight elasticity and 5 as a commercial bread flour dough with very good handling properties and elasticity.

[b] Baked by the 10-g baking procedure.

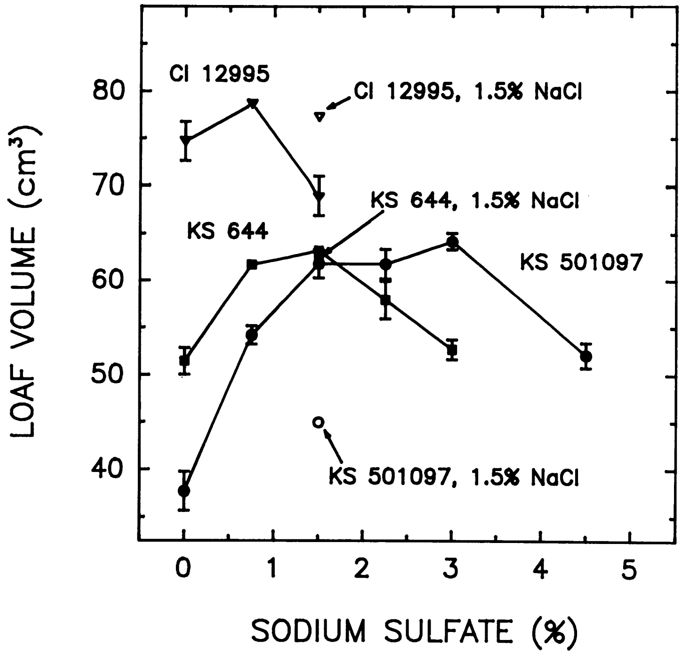

Fig. 6. Effect of sodium sulfate on the loaf volume of flours of varying baking quality. The effect of NaCl for each flour is shown as a control. Error bars are ± standard deviation.

chaotropic salts increased the strength of each dough, but the order of increasing flour strength followed the order of the original strength of the flours: CI 12995 > KS 644 > KS 501097. The less chaotropic salt (Na_2SO_4) strengthened dough more than the more chaotropic salt (NaCl) at the same level.

Baking Properties

The KS 501097 (poor quality) dough without salt or with 1.5% NaCl or 0.75% Na_2SO_4 was resistant to extension, but it was not elastic and handled like clay or putty. With increased levels of Na_2SO_4, the dough became more extensible and more elastic. When 4.5% Na_2SO_4 was added, the extensibility and elasticity of the KS 501097 dough was close to those of a good-quality flour dough. The CI 12995 (good quality) flour dough with 1.5% NaCl was extensible and elastic with good dough-handling properties. As the level of Na_2SO_4 was increased, the dough elasticity increased. When 1.5% or more Na_2SO_4 was added, the CI 12995 dough became too elastic for breadmaking (bucky). The viscoelastic properties of dough from KS 644 flour (intermediate quality) with 1.5% NaCl were between those of KS 501097 and CI 12995 flours. KS 644 flour was improved by increased Na_2SO_4 levels. However, when the concentration of Na_2SO_4 was higher than 1.5%, the KS 644 dough became too elastic to make bread.

The gas-retaining ability of KS 501097 (poor quality) dough was significantly improved by the addition of salts, as shown by proof height in Table VII. Doughs from KS 501097 flour containing 0.75–3.0% Na_2SO_4 gave the same gas retention properties during fermentation and proofing as did CI 12995 (good quality) dough containing 1.5% NaCl. However, the KS 501097 doughs had smaller oven spring than did CI 12995 dough (Table VII). The oven spring of the KS 501097 dough increased with increased levels of Na_2SO_4. However, at 4.5% Na_2SO_4, smaller proof heights and less oven spring were observed.

Each of the three flours studied responded differently to different salt levels. The poorer the original flour, the more salt was needed to give a good proof height and larger loaf volume (Fig. 6). In addition, the crumb grain of KS 501097 (poor quality) bread was significantly improved by the addition of Na_2SO_4, but it was still open and coarse with thick cell walls compared with the CI 12995 (good quality) loaf.

Therefore, when 1.5% NaCl was replaced by 1.5% Na_2SO_4, mixing time, extensibility, gas-retaining ability, and loaf volume of the poor-quality flour dough increased. As shown by many workers, neutral salts could change the hydrophobic interactions between gluten proteins (Bennett and Ewart 1965; Preston 1981; Danno and Hoseney 1982; Salovaara 1982; Kinsella and Hale 1984; Preston 1984, 1989). This improvement by strong salting-out salt supports the findings of Huebner (1970) and Chung and Pomeranz (1979) that the gluten proteins from the poor-quality flour were less hydrophobic than those from the good-quality flour. It also supports the suggestion by Bernardin and Kasarda (1973) that the hydrophobic interactions between proteins are important to bread quality.

This study also showed that the improvement on baking quality by salt was limited. The observation that KS 501097 (poor quality) and KS 644 (intermediate quality) doughs with added Na_2SO_4 failed to give large oven spring indicates that other factors besides hydrophobic interaction affect the baking properties of flours.

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[Received November 30, 1990. Revision received December 31, 1991. Accepted January 6, 1992.]