Sensory Limitations to Replacement of Sodium with Potassium and Magnesium in Bread

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ABSTRACT

Five, 10, 20, and 40% of the normal sodium chloride content in bread (2.0%, flour weight basis) was replaced with equivalent amounts of potassium chloride and three magnesium salts (chloride, sulfate, and acetate). Triangle tests showed that potassium chloride (20%) and magnesium chloride and acetate (10% each) can be substituted in bread without causing a deleterious change in flavor. Bread with no significant differences in taste compared to the reference could be baked even when 24 and 12% of the cations was replaced with equivalent amounts of potassium and magnesium chloride, respectively. The sodium content of the bread was then 320 mg/100 g of bread (36% mb), which was 64% of the reference bread. The potassium content was 2.8 times higher and the magnesium content 2.3 times higher (290 mg and 55 mg/100 g bread, respectively) than that of the reference bread, thus representing concentrations normally found in dark breads. The results show that the sodium content of bread may possibly be lowered by about one third with no significantly detectable disadvantage in bread taste, while the content of the nutritionally favorable potassium and magnesium can be increased two- to threefold.

Cereal grain products contribute about one fourth of the average sodium intake in Western diets. In baking, sodium chloride is an essential ingredient that acts as a flavor enhancer and dough stabilizer. Sodium from the common salt sodium chloride is by far the most abundant mineral added to bread. A reduction in sodium intake has been recommended (Senate Select Committee 1977). Recent evidence suggests that sufficient potassium intake may help to prevent hypertension in humans (Parfrey et al 1981). In the therapy of hypertensive patients on diazide diuretics, supplements of potassium and magnesium are often included to restore the mineral balance during medical care. Fortification of cereal grain products with magnesium has been proposed (NAS/NRC 1974).

Replacing 20–40% of sodium chloride with potassium chloride or certain magnesium salts is feasible and does not significantly affect the technological properties or baking performance of bread dough (Salovaara 1982a). However, salts of potassium and magnesium have a bitter taste and are thus unpalatable. A 40% replacement of sodium with magnesium salts or potassium chloride gave a poor bread flavor (Salovaara 1982a, 1982b). Bread baked with potassium chloride instead of sodium chloride left an undesirable aftertaste (Lorenz et al 1971).

Ranhotra et al (1976) found that fortification of bread by adding 44.1 mg of magnesium per 100 g of flour as oxide, hydroxide, or carbonate caused a slightly deleterious effect on bread flavor. They concluded that various magnesium compounds need to be examined in greater detail to fully assess their potential in bread fortification and their adverse effect on flavor. The purposes of the present study were to determine, by sensory evaluation, the extent to which the sodium chloride in bread can be replaced by potassium chloride or certain magnesium salts without causing any noticeable change in taste or odor or both and to determine corresponding mineral ratios in white wheat bread.

MATERIALS AND METHODS

Wheat Flour

Commercial wheat flour A (Salovaara 1982a) was used. Moisture content of the flour was 14.0%, and protein and ash contents were 13.1 and 0.68% (db). Sodium, potassium, magnesium, and calcium contents of the flour were 1, 128, 33.8, and 18.4 mg/100 g (14%, mb). Additional tests were made later with the same flour type but with a moisture content of 13.6% and protein and ash contents of 12.0 and 0.66% (db).

Sodium Chloride Replacement

The salts used were sodium chloride, potassium chloride, magnesium chloride hexahydrate, magnesium sulfate heptahydrate, and magnesium acetate tetrahydrate. All the salts were analytical reagent-grade compounds or fulfilled the purity demands of FAO/WHO.

In the reference bread, 2.0% of sodium chloride of the flour weight was used, representing approximately 1.35±0.02% in the final bread. Partial replacement (40, 20, 10, and 5%) of the sodium chloride was carried out by substituting 40, 20, 10, or 5% of the sodium with equivalent amounts of potassium or magnesium. The resulting breads were tested for possible differences in taste or odor or both as compared to the reference. Potassium chloride and magnesium salts were also used in combinations to determine the highest possible level at which they could replace sodium without affecting taste.

Formulation and Baking Procedures

A simple baking formula with the following ingredients was used: 1,250.0 g of flour (100%), 793.0 g of water (63.4%), 62.3 g of yeast (5%), 12.5 g of sugar (1%), 12.5 g of shortening (1%), and 25.0 g of sodium chloride (2% in reference formula).

The ingredient additions were the same as in the Rapid-Mix-Test procedure described by Pelshenke et al (1978). The amount of water was obtained from the farinograph absorption of the flour. The dough was mixed for 1 min in an intensive mixer described by Pelshenke et al (1978). Dough temperature was adjusted to 28 ± 0.5° C. Floor time was 30 min at 32° C. Scaling weight was 172 g, corresponding to 100 g of flour. The dough was molded into elongated rolls and proofed for 70 min at 32 ± 1° C in a fermentation chamber having 80 ± 5% relative humidity (rh). The breads were baked for 15 min at 240° C. After cooling for 2 hr, the breads were stored in plastic bags and kept frozen at −20° C for 1–10 days before the triangle tests.

In replicate tests, the breads were baked using flour that had a lower farinograph water absorption capacity (60.3%). Scaling weight in breadmaking was now 350 g. The doughs were molded into elongated rolls. Fermenting times were now adjusted to ~50 min by a professional test baker. Breads were baked for 20–22 min at 230° C. These changes in the baking procedure also ensured that the calculated salt concentrations in the baked product were nearly equal, regardless of whether A or B flour (Salovaara 1982a) was used (1.35 ± 0.02% NaCl in the reference bread).

General Bread Quality Evaluation

In replicate triangle tests with the above two loaves, two more loaves of the same scaling weight (350 g), fermentation times, and baking times were prepared from the same doughs for control volume measurements and general bread quality evaluation. Bread volumes were measured by the rapeseed-replacement method. The scores for general appearance (break and shred, crust and crumb color, grain and texture) and flavor were given separately by two baking technologists.

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Triangle Tests

A panel of 12–15 people (9–11 women and 3–4 men) consisting of laboratory personnel and advanced students in food technology was used. All the panelists were experienced in the triangle test and sensory evaluation of foods. Some members of the original group of 15 panelists could not participate in all of the sessions.

After about 1 hr of thawing at room temperature, the breads were mechanically sliced to a 12-mm thickness. The slices were placed in coded plastic petri dishes and presented to the panelists twice within 4 hr. Essential parts of the tests (10 and 20% replacement and certain combinations) were replicated with breads from a replicate baking. Three or four triangles were presented at each session. The order of the samples was randomized for days and panelists. Filtrated (active carbon) tap water (23° C) was available in drinking glasses for rinsing the mouth.

For testing off-odor in breads, the bread samples were cut into small cubes and stored in 200-ml covered glass jars at 37° C for 30 min before presentation to the panelists for the odor test.

All tests were performed in a room having individual compartments for the panelists. Normal electric lighting was used. The sessions took place daily from 10:00–11:30 a.m. and from 12:30–2:00 p.m. The significance of the correct judgments was evaluated using the tables by Roessler et al (1978).

TABLE I
Data of External Characteristics of Breads Baked with 10 and 20% Sodium Chloride Replacement and Three Other Salt Combinations

	External Characteristics		Flavor/Off-Flavor	
Replacement System[a]	Volume (cc)	Score[b]	Score[b]	
Reference	1,630	4	4	Description
10% KCl	1,660	3	4	···
20% KCl	1,650	3	3	insipid, bland
10% $MgCl_2 \times 6\ H_2O$	1,450	3	4	···
20% $MgCl_2 \times 6\ H_2O$	1,640	3.5	3	insipid, bland
10% $MgSO_4 \times 7\ H_2O$	1,510	4	4	···
20% $MgSO_4 \times 7\ H_2O$	1,700	4	3	flat, bland
10% $Mg(OAc)_2 \times 4\ H_2O$	1,660	3	3	···
20% $Mg(OAc)_2 \times 4\ H_2O$	1,630	3.5	3	flat, sour
KCl + $MgCl_2 \times 6\ H_2O$[c]	1,660	4	2	musty, flat
KCl + $MgSO_4 \times 7\ H_2O$[c]	1,660	4	3	musty, flat
KCl + $Mg(OAc)_2 \times 4\ H_2O$[c]	1,710	4	3	sour

[a] Percentage of sodium ions of the reference bread replaced by equivalent amounts of the salts mentioned.
[b] 4 = very good, 3 = good, 2 = moderate, 1 = unsatisfactory.
[c] Composition of the salt combinations by weight: 65% NaCl, 25% KCl, and 10% $MgCl_2 \times 6\ H_2O$, or $MgSO_4 \times 7\ H_2O$, or $Mg(OAc)_2 \times 4\ H_2O$, corresponding to replacement levels of 21.7% KCl + 6.4% $MgCl_2 \times 6\ H_2O$, or 22.0% KCl + 5.3% $MgSO_4 \times 7\ H_2O$, or 21.8% KCl + 6.1% $Mg(OAc)_2 \times 4\ H_2O$, respectively.

TABLE II
Detection of Difference in Bread Flavor Affected by Partial Sodium Chloride Replacement[a]

	Number of Judgments for Bread Flavor with Replacement of NaCl by			
Replacement Level (%)[b]	KCl	$MgCl_2 \times 6\ H_2O$	$MgSO_4 \times 7\ H_2O$	$Mg(OAc)_2 \times 4\ H_2O$
5	7/30	8/28	13/24*	12/28
10	11/28	24/54	23/47*	20/41
20	18/56	26/54*	25/51*	30/56**
40	15/28*[c]	23/30***	17/28**	21/30***

[a] Number of judgments correct divided by total in triangle tests.
[b] The proportion of sodium ions of the reference bread (2.0% NaCl, or 0.3422 mol/kg on flour basis) replaced by equivalent amounts of the potassium or magnesium salt mentioned).
[c] * = significant at $P = 0.05$, ** = significant at $P = 0.01$, *** = significant at $P = 0.001$.

Off-Flavor Description

Verbal descriptions of off-flavors of coded samples were given by two baking technologists.

Analytical Methods

Moisture of the flours was determined after drying the samples (5-g) for 60 min at 130° C. Protein was determined by the Kjeldahl procedure (AOAC 1975) using the 5.7 conversion factor for nitrogen. Ash content was determined according to the AOAC (1975) magnesium acetate method. Water absorption capacity of the flour and moisture content of the breads were determined according to the AACC (1962) procedures.

Sodium, potassium, magnesium, and calcium contents of the flour and breads were determined using atomic absorption spectrophotometry. Two loaves of each sample were sliced for the mineral content assay. Slices cut from the middle and near the ends of the loaves were homogenized in a Bamix mixer (ESGE AG, Mettlen, Switzerland). Approximately 3 g of flour or homogenized bread was ashed in a muffle oven at 550° C for 16 hr using a silica crucible. The ash was dissolved in a few milliliters of hot 4*N* HCl. The solution was transferred to a 50-ml flask. The crucible was rinsed with hot water, which was poured into the flask. The final HCl concentration was adjusted to ~0.5 N. Sodium, potassium, calcium, and magnesium contents were determined by atomic absorption spectrometry using a Perkin-Elmer 603 instrument and an acetylene flame. In the determination of calcium content, a lithium ion addition against interferences was made.

RESULTS

General Bread Quality

Volumes and scores for general bread appearance and flavor as well as verbal off-flavor descriptions of the breads baked by 10 and 20% replacement with sodium chloride and three combinations are presented in Table I. The 20% replacement was described as bland, flat, sour, and musty, but a 10% replacement was unnoticed in this simple test.

Results of Triangle Tests

The lowest replacement levels (5 and 10%) did not affect the flavor of the breads, regardless of the salt used, except for magnesium sulfate (Table II). All salts gave a significant off-flavor at the highest replacement level of 40%, spontaneously described by assessors as bitter, sour, musty, and cloying. Twenty percent replacement with magnesium salts gave a flat and bland off-flavor, but potassium chloride did not. The proportion of correct judgments was generally slightly higher for the magnesium salts than for the potassium chloride, indicating differences in the flavor of these cations in equal concentrations. The significant differences detected with magnesium sulfate at 5 and 10% replacements but not with magnesium chloride or acetate may indicate the role of these anions in bread flavor as well.

No difference in bread odor was detected even at an elevated temperature (37° C) when 20% of the sodium chloride was replaced with potassium chloride or when 10% was replaced with magnesium chloride and magnesium sulfate (Table III).

TABLE III
Detection of the Difference in Bread Odor Caused by Partial Sodium Chloride Replacement[a]

Replacement Salt	Replacement Level[b] (%)	Number of Judgments Correct/Total	Significance[c]
KCl	20	11/24	NS
$MgCl_2 \times 6\ H_2O$	10	10/24	NS
$MgSO_4 \times 7\ H_2O$	10	8/24	NS

[a] Results of triangle tests. Samples tempered at 37°C for 30 min.
[b] The proportion of sodium ions by the reference bread (2.0% HCl, or 0.3422 mol/kg on flour basis) replaced by equivalent amounts of the potassium or magnesium salts mentioned).
[c] NS = not significant.

TABLE IV
Detection of the Difference in Bread Flavor as Affected by Partial Sodium Chloride Replacement with Combinations of Potassium Chloride and Some Magnesium Salts[a]

Replacement Salts	Number of Judgments for Bread Flavor with NaCl Replacement Levels (%)[b]									
	5 + 5	10 + 5	20 + 5	y + z[c]	24 + 6	26 + 6	24 + 8	24 + 10	24 + 12	24 + 14
KCl + $MgCl_2 \times 6\ H_2O$	9/26	8/30	15/30[d]	16/52	6/24	20/24***	/24	11/24	20/46	14/24*
KCl + $MgSO_4 \times 7\ H_2O$	–[e]	–	12/26	26/52**	–	–	–	–	19/38*	–
KCl + $Mg(OAc)_2 \times 4\ H_2O$	–	–	12/30	13/44	–	–	–	–	16/28**	–

[a] Number of judgments correct divided by total in triangle tests.
[b] The proportions of sodium ions of the reference bread (2.0% NaCl, or 0.3422 mol/kg on flour basis) replaced with equivalent amounts of potassium chloride and magnesium salt.
[c] Composition of the salt combinations by weight: 65% NaCl, 25% KCl and 10% $MgCl_2 \times 6\ H_2O$, or $MgSO_4 \times 7\ H_2O$, or $Mg(OAc)_2 \times 4\ H_2O$, corresponding to replacement levels of 21.7% KCl + 6.4% $MgCl_2 \times 6\ H_2O$, or 22.0% KCl + 5.3% $MgSO_4 \times 7\ H_2O$, or 21.8% KCl + 6.1% $Mg(OAc)_2 \times 4\ H_2O$, respectively.
[d] * = significant at $P = 0.05$, ** = significant at $P = 0.01$, *** = $P = 0.001$.
[e] – = test not performed.

Sodium chloride was also replaced with certain combinations of potassium chloride and magnesium salts. The results are presented in Table IV. The highest level of replacement that did not affect flavor in triangle tests was a combination in which 24% of the sodium chloride was replaced with the same amount of potassium chloride and a further 12% with magnesium chloride (24 + 12 combination).

A higher potassium level of 26% but with only 6% magnesium (26 + 6 combination) led to a significant number of correct judgments ($P < 0.001$). Also, 24% potassium with 14% magnesium (24 + 14 combination) was found to cause a difference in taste ($P < 0.03$). With the highest undetected replacement with potassium and magnesium chlorides (24 + 12 combination), a difference in taste was detected when magnesium sulfate or magnesium acetate was used instead of magnesium chloride (Table IV).

The combinations marked "y + z" in Table IV represent weight distributions of 65% sodium chloride, 25% potassium chloride, and 10% magnesium salt (magnesium chloride hexahydrate, magnesium sulfate heptahydrate, or magnesium acetate tetrahydrate). The breads containing magnesium sulfate affected flavor ($P = 0.01$), but those baked with the other magnesium salts did not.

Mineral Contents and Ratios in Breads

In the reference bread, the analyzed concentration of sodium (500 mg/100 g) was slightly lower than the theoretical calculated value based on the amount of sodium chloride (536 mg/100 g). The other ingredients, including yeast, made only a minor contribution to the sodium content in bread, but their contribution to the contents of the other minerals was greater.

In the reference bread, the analyzed concentration of sodium (500 mg/100 g) was almost five times as high as that of potassium, as shown in Table V. The molar ratio of sodium to potassium was 8.2:1. The highest replacement level found not to affect bread flavor resulted in a reduction of the sodium content by 36%, from 500 mg to 320 mg per 100 g of bread. At the same time, the potassium content of the bread increased 2.8-fold and the magnesium content 2.3-fold. A considerable reduction in the sodium content (26%) and a simultaneous increase in the potassium and magnesium contents (2.6-fold and 1.7-fold, respectively) were also attained when using a somewhat lower substitution level (Table V).

DISCUSSION

Changes in flavor limit the extent to which sodium chloride can be replaced with potassium chloride or magnesium salts in bread. The change in flavor is probably due to a reduction of saltiness, expressed as a bland and flat taste, and to the musty, sour, bitter, and cloying off-flavor. Despite its bitter and unpalatable taste, potassium chloride could replace 20% of the sodium equivalents normally added to bread as sodium chloride without causing a significant difference in flavor. Replacing 40% of the sodium in this way gave an undesirable off-flavor that would be barely tolerable in commercial breads.

TABLE V
Concentration of Sodium, Potassium, Calcium, and Magnesium and the Molar Ratios of the Cations in the Breads

Sample[a]	Concentration (mg/100 g)[b] and Molar Ratios of the Cations					
	Na	K	Na:K	Ca	Mg	Ca:Mg
Theoretical[c]	536	84	10.9:1	12.0	15:6	0.47:1
Reference[d]	500	104	8.2:1	14.3	23.8	0.36:1
24% KCl, 12% $MgCl_2$[e]	320	290	1.8:1	13.7	55.1	0.15:1
21.7% KCl, 6.4% $MgCl_2$[f]	368	274	2.3:1	14.4	40.0	0.21:1

[a] Percentages indicating the proportion (%) of sodium ions replaced with equivalent amounts.
[b] Dry matter content of the breads 63–64%.
[c] Added NaCl and mineral concentrations found in flour.
[d] 2.0% NaCl on flour weight, representing approximately 1.35% in bread.
[e] Corresponding weight distribution: NaCl 55.4%, KCl 26.5%, $MgCl_2 \times 6\ H_2O$ 18.1%.
[f] Corresponding weight distribution: NaCl 65%, KCl 25%, $MgCl_2 \times 6\ H_2O$ 10%.

Magnesium salts affected bread flavor in lower concentrations than potassium chloride did. Data obtained with 5 and 10% replacements as well as salt combinations indicate that anions also have a role in flavor. Ranhotra et al (1976) reported that certain magnesium compounds including chloride or sulfate have a slightly better flavor than others such as magnesium carbonate or oxide when used for magnesium enrichment in bread. The concentrations applied by Ranhotra et al (1976) (44.1 mg of added magnesium) represented approximately an 11% replacement level in the present study. In commercial use, magnesium sulfate heptahydrate has some advantages over magnesium chloride hexahydrate in terms of price and hygroscopic properties.

The mineral content of bread was balanced markedly when a part of the sodium chloride was replaced with potassium and magnesium chlorides. In certain combinations, even one third of the normal sodium chloride could be replaced without affecting the bread flavor. The potassium and magnesium contents of the breads were increased to a level representing that of dark European breads, which sometimes contain 230–380 mg of potassium and 55–75 mg of magnesium per 100 g of fresh bread (Varo et al 1980). By replacing part of the sodium chloride with potassium and magnesium chlorides, the magnesium content of bread was almost doubled compared to the recommended level for fortified breads in the United States (NAS/NRC 1974). The higher ratio of magnesium to calcium in bread should be especially beneficial in diets in which excessive milk consumption causes an imbalance in the calcium to magnesium ratio.

In the present study, the ratio of sodium to potassium was considerably changed in favor of potassium, from a ratio of about 8:1 to about 2:1, without affecting the flavor of bread. Such bread might be used especially well by those suffering from high blood pressure. When applied to other bread types, the addition of less salt and the use of flours with a higher extraction rate and higher initial potassium content could adjust the ratio of sodium to potassium even further in favor of potassium. This was done in a study with whole meal sour rye bread (Salovaara 1982b). Commercially produced white breads often contain considerable amounts of sugar and milk in the form of nonfat dry milk, which may mask off-flavors affected by the potassium and magnesium salts.

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