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Sodium Gluconate and Potassium Gluconate as Substitutes for Sodium Chloride in Breadmaking

Hiroyuki TAKANO[1] and Ryouko KONDOU[2]

[1]*National Food Research Institute, Tsukuba Science City, Ibaraki, 305-8642, Japan*
[2]*Fujisawa Pharmaceutical Co., LTD., 5-2-3 Tokodai, Tsukuba, Ibaraki, 300-2698, Japan*

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Sodium gluconate (Na-gluconate) and potassium gluconate (K-gluconate) were used as NaCl substitutes in breadmaking to determine their potential usefulness in preparing reduced-sodium bread and non-sodium bread. Replacement of 75% of the NaCl by Na-gluconate and of 50% by K-gluconate had no effect on rheological properties of dough as measured by Brabender Extensograph. Replacement of 100% of the NaCl by either Na-gluconate or K-gluconate resulted in decreased resistance to extension, but the decreased resistance to extension had no effect on dough handling properties. Expansion of white bread dough (5% sugar, flour weight basis) increased with the proportion of NaCl replaced by Na-gluconate or K-gluconate. The patterns of carbon dioxide production during fermentation of non-sugar bread dough showed that as the proportion of Na-gluconate or K-gluconate increased, the time required to complete fermentation decreased, and the fermentation pattern showed a gradual resemblance to that seen in non-sugar bread dough without NaCl. In white bread, complete replacement of NaCl (2%, flour weight basis) by Na-gluconate or K-gluconate did not cause a difference in loaf volume, nor did it have any significant effect on overall desirability. Shelf life of white bread was not affected by substitution of Na-gluconate or K-gluconate for NaCl. Based on these results, it is possible to make reduced-sodium bread using Na-gluconate, and non-sodium bread using K-gluconate, incorporating each gluconic acid salt in an amount equal to 1.8% of flour weight in white bread.

Keywords: bread, gluconic acid salt, substitutes for NaCl, reduced-sodium bread, non-sodium bread

Sodium chloride is a very important and a major ingredient in bakery products. The function of salt in bakery products is to enhance the flavor (not a salty flavor), control the rate of fermentation of a yeast-leavened product, improve bread dough to insure good handling properties and obtain superior quality (internal grain and texture) of the final product (Vetter, 1981). However, greater intake of sodium contributes to the increasing incidence of hypertension in the U.S.A, Japan and other developed countries (Dahl, 1972, Weber & Laragh 1978, Morgan *et al.,* 1978).

Finney (1984) reported that 1.5–1.75% NaCl could be used in white bread. Stroh *et al*. (1985) found that the bitter flavor of KCl could be masked with NaCl. There have been other studies of NaCl substitutes (Salovaara, 1982a, 1982b; Wyatt, 1983), but none useful in preparing white bread without sodium, or with a reduced amount of sodium, have been found. Takano *et al*. (1996) reported that the amount of NaCl used in bread could be reduced from 2% to 1.25–1.5%, and that if 0.25% to 0.5% KCl was added, the amount of NaCl could be reduced to 1%. Na-gluconate and K-gluconate were found to be useful substitutes for NaCl. Gluconic acid is used as a flavoring agent (Boutraux, 1978). Asano *et al*. (1994) found that gluconic acid promotes the growth of *Lactobacillus bifidus*, as do oligosaccharides. Furthermore, Morita *et al*. (1994) reported that calcium gluconate improves bread dough. So far, there have been no reports of the use of Na-gluconate or K-gluconate as substitutes for NaCl. In the present study, the authors tested salts of organic acids to find useful substitutes for NaCl so that baked products could be prepared from wheat flour with no or with a reduced amount of sodium.

E-mail: htakano@nfri.affrc.go.jp

Materials and Methods

Bread ingredients and baking procedure The flours used in the study were commercial wheat flours for breadmaking (protein content, 12.4%). The NaCl substitutes were Na-gluconate and K-gluconate, both obtained from Fujisawa Pharmaceutical Co., Ltd. Japan. Other ingredients were NaCl (Pharmacopoeia of Japan), shortening for breadmaking (NOF Co., Tokyo), sugar (commercial sucrose), and breadmaking yeast (commercial compressed yeast, Oriental Yeast Industry Co. Tokyo).

White bread was prepared using a straight-dough method. Loaves of bread were evaluated initially and on their shelf life. The white bread formula contains NaCl, which is a common bread ingredient. This formula required the following ingredients for every 100 g of breadmaking flour (13.5% moisture basis): 5 g of sugar, 2 g of NaCl, 5 g of shortening, 2 g of compressed yeast (67% moisture basis), and 66 ml of water (optimum quantity). In order to test the effects of Na-gluconate and K-gluconate, each gluconic acid salt was substituted for 50% to 100% of the NaCl in the above formulas. The materials were mixed to the optimum development of the dough in a pin mixer (National Mfg. Co., Lincoln, Nebraska). The dough was fermented at 30°C with 75% relative humidity for 115 min with punching at 70 min and 100 min. At the end of fermentation, the dough was sheeted through rolls set at 1/4 and 1/4 inch and molded with a dough molder

(National Mfg. Co.). The molded dough was then panned and proofed at 38°C with 85% relative humidity at 55 min. Bread was baked at 200°C for 25 min.

Viscosity and rheological properties The NaCl, NaCl with either Na-gluconate or K-gluconate, and Na-gluconate or K-gluconate alone were used in an amount equal to 2% of the flour weight, and the effects on viscosity and rheological properties of dough were measured with an amylograph and extensograph (Brabender OHG, Duisburg, Germany), respectively.

Fermentation ability of bread dough The effect of substituting Na-gluconate or K-gluconate for NaCl on dough expansion of 5% sugar bread dough (white bread formula) was determined by measuring expansion of the dough volume during fermentation with an Expandougraph AF-1010 (Atto Co. Tokyo) using a cylinder, according to Evaluation Methods of Bakers' Yeast (II-1 and II-2, Japan Yeast Industry Association, 1996).

In addition, the effect of substituting Na-gluconate or K-gluconate for NaCl on carbon dioxide production of sponge dough during fermentation at 30°C was determined. Sponge dough (20 g of wheat flour, 2% of compressed yeast, and 67% water) was prepared with 2% of salt (NaCl alone, NaCl with either Na-gluconate or K-gluconate, or Na-gluconate or K-gluconate alone) and without any salt, and the amount of carbon dioxide produced by these doughs during fermentation was measured with a Fermograph AF-1000 (Atto Co., Hino *et al*., 1988) according to Evaluation Methods of Bakers' Yeast (III-2, Japan Yeast Industry Association, 1996).

Bread quality Quality of white bread stored for 24 h was evaluated according to Evaluation Methods of Bakers' Yeast (V-4, Japan Yeast Industry Association, 1996). After baking, loaf volume and specific loaf volume (volume per unit weight) were determined. Loaf volume was measured with a 3D-laser analyzer (SELNAC-VM, ASTEX Co., Komae, Tokyo). Twenty-four hours later, bread quality was evaluated according to a scoring system in which a maximum of 50 points each were given for external appearance (specific loaf volume, 30; evenness of crust color, 10; symmetry of form, 5; character of crust, 5) and internal characteristics (grain, 10; crumb color, 5; texture, 5; odor, 15; taste, 15). The evaluations were based on the total score as follows: lower than 60 points, *very poor* (*E*); 61 to 70 points, *poor* (*D*); 71 to 80 points, *satisfactory* (*C*); 81 to 90 points, *good* (*B*); and more than 90 points, *excellent* (*A*).

Staling and shelf life of white bread After baking, 8 loaves of white bread for each salt combination tested were allowed to cool at room temperature (25°C) for 1 h. Then each loaf was placed in a polyethylene bag, and the bag was sealed. The bagged loaves were stored in an incubator at 30°C for shelf life studies.

The rate of staling was determined by measuring the internal crumb firmness of bread with a baker's compressimeter (Wallace & Tiernan Co., Newark, NJ) based on Approved Method 74-10A (AACC, 1969) after bread had been stored for 24, 48, 72 and 96 h. Four loaves of bread were used each time.

Shelf life was evaluated by examining the surface of 4 loaves of bread for contamination by microorganisms during the 8-day storage period. An assessment of +1 was made if microbial contamination on the surface was found on only 1 of the 4 loaves, and an assessment of +2 was made if microbial contamination was found on the surface of all the loaves.

Statistical analysis Results of the bread dough expansion value and specific loaf volume were calculated as average and standard deviation. The result of the bread dough expansion value for each fermentation time and loaf volume were statistically analyzed by an Excel 2000 (Microsoft Office 2000, Microsoft, Tokyo); Duncan's multiple range test was performed..

Results and Discussion

Viscosity The Brabender amylograph was used to determine the effect of the NaCl substitutes Na-gluconate and K-gluconate on viscosity. Normally, viscosity is measured in the absence of salt, but in this study, the measurements were made using 65 g of wheat flour (13.5% mb) and 2% salt (flour weight basis), with NaCl alone, NaCl with either Na-gluconate or K-gluconate, Na-gluconate or K-gluconate alone or without any salt. The results are summarized in Table 1. Compared to the values obtained in the absence of salt, addition of NaCl in an amount equal to 2% of the flour weight resulted in an increase in the gelatinization temperature from 55.5°C to 59.0°C, and in the maximum viscosity from 455 BU to 540 BU. As increasing amounts of Na-gluconate or K-gluconate were substituted for NaCl, maximum viscosity decreased and gelatinization tended to occur at lower temperatures. When Na-gluconate or K-gluconate was used alone, the maximum viscosity and gelatinization temperature values were close to those obtained without addition of salt; the maximum viscosity was 460 BU with both gluconic acid salts, while the gelatinization temperature was 56.0°C with Na-gluconate and 57.5°C with K-gluconate. These results suggest that NaCl may control the α-amylase or β-amylase activity in flour or the rate of swelling of sound starch granules. Furthermore, because gelatinization occurs at lower temperatures and

Table 1. Effect of substituting Na-gluconate or K-gluconate for NaCl on the Amylograph and Extensograph properties.

	NaCl+Na-gluconate[a]					NaCl+K-gluconate[a]		
	0.0+0.0	2.0+0.0	1.0+1.0	0.5+1.5	0.0+2.0	1.0+1.0	0.5+1.5	0.0+2.0
Amylograph values								
Gelatinization temperature (°C)	55.5	59.0	58.5	57.0	56.0	58.0	57.0	57.5
Maximum viscosity (BU)	455	540	520	480	460	530	490	460
Maximum viscosity temperature (°C)	90.5	90.5	90.5	90.5	90.5	90.5	90.5	90.5
Extensograph values (135 min values)								
Resistance to extension (R: BU)	–	600	600	595	520	605	545	485
Extensibility (E: mm)	–	182	177	193	190	189	184	195
Ratio figure (R/E)	–	3.3	3.4	3.1	2.7	3.2	3.0	2.5
Area (cm^2)	–	153	147	162	139	157	141	128

[a]flour weight basis (%).

maximum viscosity is decreased when Na-gluconate or K-gluconate is used in place of NaCl, it seems that swelling of sound starch granules occurred more rapidly in the presence of these substitutes, suggesting that it may be possible to reduce baking time by substituting Na-gluconate or K-gluconate for NaCl.

Rheological properties Brabender Extensograph measurements were used to determine the effect of the two NaCl substitutes on rheological properties of dough. The dough used for these measurements contained 2% salt (flour weight basis), consisting of NaCl alone, NaCl with either Na-gluconate or K-gluconate, or Na-gluconate or K-gluconate alone. The results are presented in Table 1. There were no differences between the rheological properties of the 2% NaCl dough and those of the doughs in which 75% of NaCl was replaced by Na-gluconate, or 50% was replaced by K-gluconate; in fact, the 135 min resistance to extension values of all these doughs were 595 BU to 605 BU. When NaCl was completely replaced by Na-gluconate or K-gluconate, resistance to extension was approximately 500 BU, which is 80 BU to 115 BU less than the value with 2% NaCl; however, a decrease of this magnitude was not sufficient to

Table 2. Effect of substituting Na-gluconate or K-gluconate for NaCl on expansion of white bread dough.

	NaCl+Na-gluconate$^{a)}$				NaCl+K-gludonate$^{a)}$		
	2.0+0.0	1.0+1.0	0.5+1.5	0.0+2.0	1.0+1.0	0.5+1.5	0.0+2.0
1st Fermentation (60 min: ml)	390±10.1^{a}	435±9.5^{b}	440±9.8^{b}	455±6.4^{b}	435±9.7^{b}	440±8.7^{b}	450±8.2^{b}
2nd Fermentation (40 min: ml)	460±6.8^{a}	480±9.6^{b}	480±9.3^{b}	485±4.2^{b}	475±6.4^{a}	475±6.3^{a}	475±6.5^{a}
3rd Fermentation (40 min: ml)	455±7.5^{a}	470±9.0^{a}	470±8.2^{a}	465±6.3^{a}	460±6.6^{a}	465±6.7^{a}	465±6.9^{a}

$^{a)}$flour weight basis (%).
Dough expansion was measured with an Expandougraph at 30°C.
Expansion value was average and standard deviation (n=5).
Superscript letters a and b are assigned when the averages differ significantly at p<0.05.

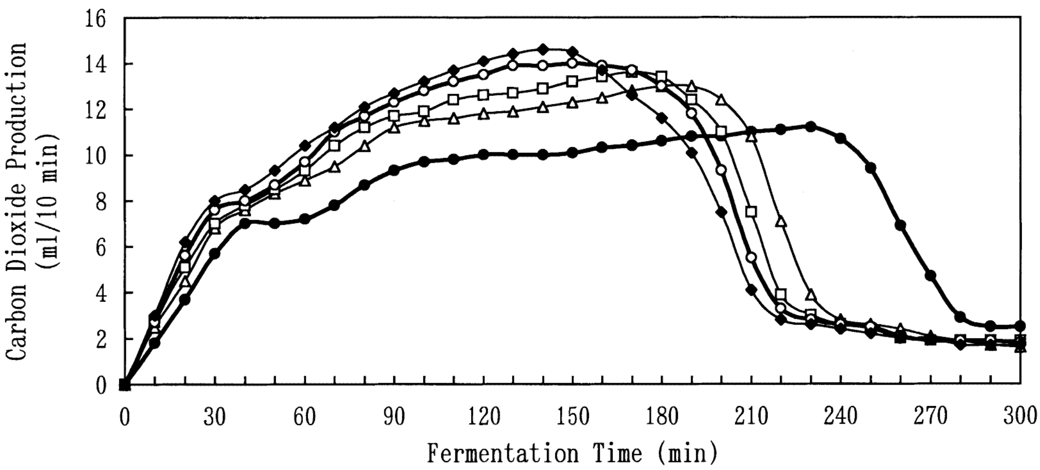

Fig. 1. Effect of NaCl and K-gluconate on carbon dioxide production during fermentation of sponge dough containing 20 g of flour.
NaCl+K-gluconate: ●=2%+0%, △=1%+1%, □=0.5%+1.5%, ○=0%+2%, ◆=0%+0%.

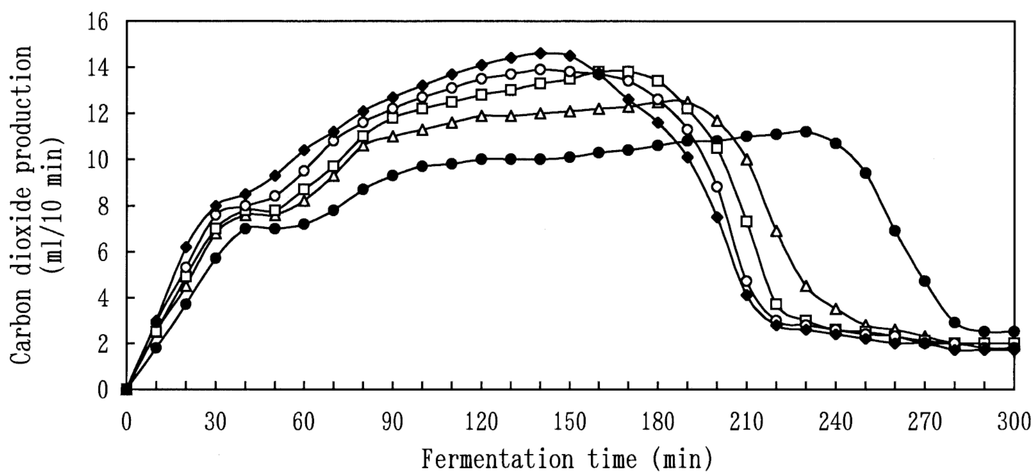

Fig. 2. Effect of NaCl and Na-gluconate on carbon dioxide production during fermentation of sponge dough containing 20 g of flour.
NaCl+Na-gluconate: ●=2%+0%, △=1%+1%, □=0.5%+1.5%, ○=0%+2%, ◆=0%+0%.

adversely affect the dough handling for breadmaking. Therefore, replacement of 100% of the NaCl by either Na-gluconate or K-gluconate seemed possible.

Expansion and fermentation pattern of bread dough The effect of substituting Na-gluconate or K-gluconate for NaCl on expansion of white bread dough was determined. Expansion of the dough was measured for 60 min during the 1st fermentation, and for 40 min during the 2nd and 3rd fermentations. The results are presented in Table 2. Expansion of the dough prepared with NaCl alone was 390 ml, 460 ml, and 455 ml during the 1st, 2nd, and 3rd fermentations, respectively. When Na-gluconate or K-gluconate was substituted for 1/2 or all of the NaCl, dough expansion increased, with values of 435–455 ml, 475–485 ml, and 460–470 ml obtained during the 1st, 2nd, and 3rd fermentations, respectively. There were significant differences in the 1st fermentation between dough prepared with NaCl alone and dough prepared with NaCl in combination with Na-gluconate or K-gluconate, or with Na-gluconate or K-gluconate alone. These results seem to indicate that Na-gluconate and K-gluconate may improve dough extensibility (results from Extensograph) and thereby increase gas retention.

Strong (1969), Vetter (1981), and Marsh (1983) reported that NaCl has a controlling effect on the fermentation of bread dough. Takano *et al*. (1996) studied the fermentation of sponge dough and reported that increasing the NaCl content of the dough resulted in greater inhibition of early fermentation and maltose fermentation, prolonging fermentation. In this study, the effects of substituting Na-gluconate or K-gluconate for NaCl on fermentation of sponge dough are shown in Figs. 1 and 2. When NaCl was used with Na-gluconate or K-gluconate, carbon dioxide production tended to increase with gluconic acid salt content both during early and late (maltose) fermentation, but since both early and late fermentation were completed sooner when Na-gluconate or K-gluconate was present, there were no salt-dependent differences in total carbon dioxide production. The fermentation pattern with Na-gluconate or K-gluconate alone approached the pattern observed when no NaCl or gluconic acid salt was used, and was exactly the opposite of the pattern when NaCl was used. For the following reason, however, we do not think that the fermentation pattern seen with the gluconic acid salts represents a disadvantage in breadmaking. NaCl has been regarded as having a controlling effect on the fermentation of bread dough because it has been used in breadmaking for many years when no substitutes were available. However, NaCl can be regarded as inhibiting the enzymatic action of yeast. From this viewpoint, gluconic acid salts can be regarded as promoting fermentation because they have almost no inhibitory action on the enzymatic action of yeast, especially the invertase activity during the early stage and maltase activity during the late stage of fermentation.

Bread quality The effect of substituting Na-gluconate or K-gluconate for NaCl on the quality of white bread was determined. When Na-gluconate or K-gluconate was substituted for more than 50% of the NaCl, baking time was reduced by about 2 min. The loaf volumes, specific loaf volumes, and bread quality scores obtained in the experiment are presented in Table 3. For white bread, there were no significant differences in loaf volume, or in specific loaf volume, between bread prepared with NaCl alone or with Na-gluconate or K-gluconate alone, and bread prepared with NaCl in combination with Na-gluconate or K-gluconate. White bread in which Na-gluconate or K-gluconate was substituted for 1/2 of the NaCl had quality scores of 81 or more points, resulting in quality evaluations of *good*. When 3/4 or all

Table 3. Effect of substituting Na-gluconate or K-gluconate for NaCl on white bread quality.

	NaCl+Na-gluconate[a]				
	2.0+0.0	1.0+1.0	0.5+1.5	0.0+1.8	0.0+2.0
Loaf volume (cm^3)	790[a]	820[a]	820[a]	800[a]	780[a]
Specific loaf volume (cm^3/g)	5.3±0.12	5.4±0.13	5.3±0.11	5.4±0.12	5.4±0.12
Bread quality score	84	83	79	77	77
	NaCl+K-gluconate[a]				
		1.0+1.0	0.5+1.5	0.0+1.8	0.0+2.0
Loaf volume (cm^3)		795[a]	795[a]	800[a]	800[a]
Specific loaf volume (cm^3/g)		5.3±0.12	5.4±0.10	5.3±0.12	5.3±0.13
Bread quality score		81	81	78	75

[a]flour weight basis (%).
Value of specific loaf volume was average and standard deviation (n=5).
Loaf volume showed no significant difference between bread prepared with NaCl alone and with others.

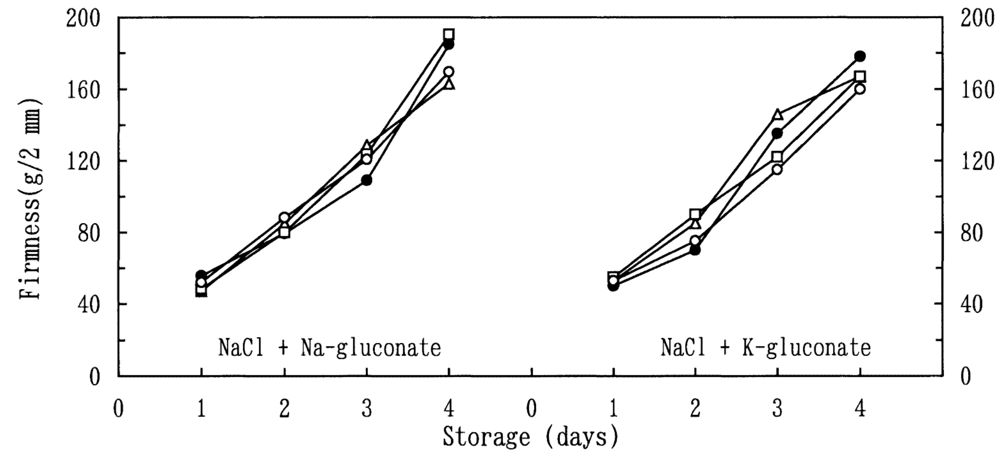

Fig. 3. Effect of substituting Na-gluconate or K-gluconate for NaCl on staling of white bread during storage at 30°C. NaCl+Na-gluconate or K-gluconate: ●=2%+0%, △=1%+1%, □=0.5%+1.5%, ○=0%+2%.

Table 4. Effect of substituting Na-gluconate or K-gluconate for NaCl on shelf life of white bread.

NaCl (%)	Na-gluconate (%)	Stored (days)					
		3	4	5	6	7	8
2.0	0	–	–	–	–	+	++
1.0	1.0	–	–	–	–	+	++
0.5	1.5	–	–	–	–	+	++
0	2.0	–	–	–	–	+	+
NaCl (%)	**K-gluconate (%)**	**Stored (days)**					
		3	4	5	6	7	8
2.0	0	–	–	–	–	+	++
1.0	1.0	–	–	–	–	+	++
0.5	1.5	–	–	–	–	+	+
0	2.0	–	–	–	–	+	+

–: microorganisms not found on loaf surface.
+: microorganisms found on loaf surface, but only a few colonies.
++: numerous microorganisms found on loaf surface.

of the NaCl in white bread was replaced by Na-gluconate or K-gluconate, the quality scores were 75 to 80 points, which was *satisfactory* quality. These results show that replacement of NaCl by gluconic acid salts in white bread did not cause problems with respect to quality. In addition, white bread was prepared using Na-gluconate and K-gluconate alone at a level of 1.5 and 1.8% (flour weight basis), and results similar to those described above were obtained (data of 1.5 not shown). These results suggest that it is possible to use Na-gluconate alone (1.5% to 1.8%) to bake reduced-sodium white bread, and K-gluconate alone to bake non-sodium bread.

White bread in which KCl was substituted for more than 1/4 of the NaCl had a bitter flavor, resulting in very poor eating quality (Takano *et al*., 1996). However, white bread prepared using Na-gluconate or K-gluconate alone does not have a bitter flavor, resulting in a satisfactory eating quality.

Staling and shelf life of white bread The effect of substituting Na-gluconate or K-gluconate for NaCl on staling of white bread was determined by measuring firmness with a baker's compressimeter after 1, 2, 3 and 4 days of storage. The results are shown in Fig. 3. Firmness increased with duration of storage, but there was almost no difference between the firmness of bread made with NaCl alone, and that of bread made with Na-gluconate or K-gluconate alone. Therefore, it can be concluded that there was no difference between staling of bread made with the gluconic acid salts, and staling of bread made with NaCl alone.

The effect of substituting Na-gluconate or K-gluconate for NaCl on shelf life of white bread was evaluated by examining the surface of loaves for contamination by microorganisms during storage. The result is presented in Table 4. No microbial contamination whatsoever was seen on any of the loaves, regardless of the salts they contained, for the first 6 days of storage. It was therefore concluded that there was no difference between the shelf life of bread made with the gluconic acid salts alone, and that of bread made with NaCl alone.

In the case of sweet bread it is also possible to use Na-gluconate to bake a reduced-sodium sweet bread, and K-gluconate alone to bake non-sodium bread (data not shown).

Conclusions

Salt (sodium chloride) is an extremely important ingredient in bread. In the present study, Na-gluconate or K-gluconate was substituted for NaCl in breadmaking, and the effects on viscosity, rheological properties, fermentation ability, workability, bread quality, staling, and shelf life were determined. No differences in workability, bread quality, shelf life, etc. were seen between bread prepared with NaCl and bread prepared with Na-gluconate or K-gluconate. It therefore seems possible to make reduced-sodium bread using Na-gluconate, and non-sodium bread using K-gluconate.

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