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Partial substitution of sodium chloride by potassium chloride in bread: effect on dough and bread properties

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RESEARCH ARTICLE

Abstract

Negative effect of sodium chloride (NaCl) consumption to health has been forcing food processors to re-formulate their products for possible reduction of Na. Reducing Na content of bread, without compromising its sensory-textural properties and the process requirements, might lead to start a low Na diet. While innovative approaches are continuously introduced for Na reduction in processed foods, a common approach is the use of various cations, like potassium, as Na substitutes. Therefore, the objective of this study was to determine the replacement ratio of NaCl with KCl in an industrial white bread production. For this purpose, white bread loaves with partial replacement of NaCl were produced using the straight-dough method. Textural properties of dough samples and sensory properties of bread loaves were determined. Bread with NaCl replacement up to 37.5% KCl was determined to have similar sensory characteristics as the control bread samples. Moreover, no significant impact on dough properties (extensibility, stickiness) was observed. Considering the convenience of replacing NaCl with KCl in industrial production and reducing Na-intake this simple approach might help preventing further health related problems.

Keywords: sodium reduction, bread, dough, sodium replacers

1. Introduction

Despite the beneficial function of salt (NaCl – sodium chloride) in food processing (including flavour formation, preservation, pro-oxidant effect, water holding capacity enhancer, etc.) and human metabolism, its negative contribution to development of high blood pressure, coronary heart diseases, cardiovascular diseases and other health conditions (Beck *et al.*, 2012; Nachay, 2013) have started forcing food processors to re-formulate their products for possible reductions in using NaCl. Hence, significance of various studies to reduce the salt level in the processed foods has become imperative (Albarracin *et al.*, 2011). This is especially valid for bread, meat, dairy and convenience food industries (Kloss *et al.*, 2015). Salt is the most widely used addition in the food industry with its low cost and various properties (Albarracin *et al.*, 2011). Salt, consisting of 40% Na and 60% Cl, is commonly used in the form of NaCl, and it provides about 90% of the Na in the human diet. The World Health Organization (WHO) recommends <2 g/day of Na (<5 g/day of dietary salt intake) (Kloss *et al.*, 2015). A significant amount of Na intake is reported to be due to consumption of processed foods (5-10% is due to the discretionary addition – Doyle and Glass, 2010), and pressure from regulatory agencies and national health organisations makes reducing Na content of the processed foods one hot topic (Katz and Williams, 2010). However, replacement of NaCl in processed foods is a quite complex issue since its use depends upon various factors from process requirement and sensory to keeping quality and safety. Therefore, as reported by Doyle and Glass (2010), efforts to reduce salt in processed foods must be balanced with the original purpose since additional techniques might then be still required to preserve quality and safety of the product/process.

For Na reduction in processed foods, while innovative options have been continuously introduced (e.g. use of salt microspheres with their reducing properties due to their structure with increased surface area to volume ratio), the common approach is still the use of NaCl substitutes, which are based on the substitute of Na with various kations, like potassium, calcium and magnesium, and/or flavour enhancers (Albaraccin *et al.*, 2011; Beck *et al.*, 2012). Among these, potassium chloride (KCl) is the most common choice to replace NaCl due to the similar effects of Na and K on the proteins. They also subsequently appear in the Hofmeister series (classification of ions for their ability to salt or salt out in proteins) (Baldwin, 1996). However, the metallic and bitter taste of K are additional factors to take into account.

Since majority of Na intake is linked with consumption of processed foods, the re-formulation of the process to reduce Na content for bread, meat, dairy and convenience food industries has become a significant objective. Considering the consumption rate of these products and their contribution to daily intake of Na (cereal and cereal products with 35% followed by meat and meat products with over 25% contribution) (Kilcast and Ridder, 2007); bread is a significant factor for dietary daily Na intake (Girgis *et al.*, 2003). Possible reduction in Na content of bread, without negatively affecting its flavour, sensory-textural properties and the technological process, might lead to a low Na diet. However, this is one difficult task to achieve since the manufacturers usually assume the NaCl usage to be vital for processing and the eventual flavour formation (Girgis *et al.*, 2003). The role of NaCl in bread production is, in fact, related with the taste and also rheological properties of the dough. Via the use of NaCl, the dough becomes stronger presumably due to shielding the charges on the proteins (Hoseney, 1990). Therefore, prevention of a flat taste with reduced NaCl usage and possible changes in the rheological properties become the key factors to achieve a Na reduced bread production.

This subject has been explored in the literature several times. Salovaara (1982a,b) replaced Na with other salts for changes in the sensory properties of bread and wheat dough rheology. Wyatt (1983) reduced NaCl in bread by 50% with no significant effect on overall desirability. Girgis *et al.* (2003) determined a one-quarter reduction in the salt content of bread without detection. Charlton *et al.* (2007) achieved partial replacement of Na with K and other salts in brown bread. Braschi *et al.* (2009) partially substituted Na with K in white bread demonstrating that this substitution can be achieved without compromising the overall acceptability. Lynch *et al.* (2009) addressed the effect of salt reduction on dough and bread characteristics. Kaur *et al.* (2011) studied the effect of NaCl replacement with mineral salts on rheological characteristics of wheat flour and demonstrated no adverse effects. Beck *et al.* (2012) offered an essential background for the effects of NaCl reduction on sensory, preservation and technological impact on yeast-leavened products. Spina *et al.* (2015) demonstrated the effect of NaCl reduction from 2 to 1% and its partial replacement with KCl and yeast extract. Sensory related studies by Salovaara (1982a); Charlton *et al.* (2007) and Braschi *et al.* (2009) indicated a possibility of replacement of NaCl by KCl without compromising the sensory properties.

Based on these studies reported in the literature, replacement of NaCl with KCl seems to be a convenient approach especially from technological point of view since Na and K ions show similar effects on the proteins with their subsequent appearance in the Hofmeister series (Baldwin, 1996) with additional equivalent antimicrobial effect on various pathogenic microorganisms (Bidlas and Lambert, 2008).

Starting from July, 2012, NaCl amount of wheat bread loaves in Turkey was reduced to 1.5% (d.b.) with a goal of 1% in the near future. With this new legislation, reducing Na amount in breads by using KCl might be a challenge due to the bitter taste / metallic flavour of KCl. Since the final NaCl content was already reduced, determining a replacement ratio without compromising the process technology and final taste of the product might be a beneficial study for the industry. Therefore, the objective of this study was to determine the replacement ratio of NaCl with KCl in the industrial production of wheat bread loaves.

2. Materials and methods

This study was completed in two stages. In the first part, the dough samples with partial replacement of NaCl (with final NaCl and NaCl+KCl concentrations to be 1.5% d.b.) with KCl were produced using the straight-dough method in an industrial scale process line. Then, textural attributes (extensibility, resistance to extension and stickiness values) of the dough samples were determined. Extensibility and resistance to extension values were preferred due to their correlation with Extensograph parameters, while stickiness values were to represent rheological properties of the dough. Following this, sensory evaluations of the produced bread loaves were carried out for external appearance, internal pore structure, taste-saltiness-bitter/metallic flavour and general acceptability. In addition, bread samples prepared with the optimum KCl replacement ratio was subjected to a triangle test for comparison with the control samples.

Materials

Commercial wheat flour (Karşıyaka Un San. Tic. A. Ş., Adana, Turkey), with 12.5% moisture and 0.55% ash (d.b.) was used throughout the study. The wet gluten, dry gluten and gluten index values were measured as 26.3, 7.3 and 61.7%, respectively, with Falling Number value of 449 s. NaCl (Merck, Darmstadt, Germany), food grade KCl (Merck, Darmstadt, Germany), compressed baker's yeast (Pakmaya Co., Izmit, Turkey) and bakery additive (contains calcium carbonate, soybean flour, mono- and diacetyl tartaric acid esters of mono- and diglycerides, citric acid, ascorbic acid, and alpha amylase) (Vatan Gida, Istanbul, Turkey) were purchased from local suppliers.

Methods

Bread production

The straight-dough method was used for the production of control and reduced Na bread loaves. An industrially used control recipe was applied in the production line in Mersin University Food Research Centre; the reduced Na bread recipes are reported in Table 1. The final concentration of NaCl in the control and NaCl and KCl concentration in the Na-reduced bread loaves were adjusted to be 1.5% (d.b.). 1.5% NaCl (reduced from 2%) in the final product is required by the Turkish Food Codex Regulation of July 2012.

Water temperature during dough preparation was adjusted to achieve a dough temperature of 21±1 °C. After mixing all ingredients for 22 min (6 min slow and 16 min fast mixing) using a spiral type mixer (SPM-40; Fimak, Konya, Turkey), the dough was proofed at 25±1 °C for 15 min. Subsequently, the dough was divided into 300 g portions, and these portions were rounded and moulded mechanically. Proof time was 45 min at 40±1 °C, and baking process was carried out at 230 °C for 12 min in a stone based multi-deck industrial bread oven (FM-180; Fimak). Following the baking process, the loaves were left to cool for 20 min, and then placed in polyethylene bags and stored at 20 °C until further sensory evaluation. All the trials were repeated in triplicate.

Dough texture analysis

Stickiness was determined by following the method of Chen and Hoseney (1995) using a texture analyser (TA-XT2, Stable Micro Systems Ltd., Godalming, UK). For this purpose, the dough sample was placed in the chamber of Stable Micro system/Chen-Hoseney Dough Stickiness Cell and closed with a die by screwing. Following this, the dough was extruded through the holes on the die by rotating the internal screw. A blade was used to discard the first extrusion off the die surface. The dough was further extruded by rotating the screw until it was about 1 mm over the die surface. After 30 s, texture analyser probe (25 mm perspex cylinder) was driven to contact the prepared dough surface, and the force required for separating the probe from the dough surface was recorded. Extensibility of the dough sample was also measured using the texture analyser (TA-XT2) equipped with a Kieffer/SMS dough and gluten extensibility rig (Kieffer *et al.*, 1998) and 5 kg load cell. The dough was pulled at a crosshead speed of 3.3 mm/s. The resistance to extension (maximum force) and extensibility (distance to break) were calculated from the force-deformation curves.

Sensory evaluation of bread

Sensory evaluation studies were carried out in two stages. In the first part, various attributes of the bread loaves were evaluated, and the formulation with the highest KCl replacement level still giving similar sensory attributes to the control bread were determined. In the second stage, the chosen formulation was evaluated in a triangle test compared with the two control samples to determine whether a difference will be detected. The control samples were the bread samples with 1.5% NaCl content.

Table 1. Formulation for control and reduced sodium bread.

Ingredient[1]	Replacement level (%)					
	0[2]	25	37.5	50	75	100
Flour	2,000	2,000	2,000	2,000	2,000	2,000
NaCl	27.3	20.5	17.1	13.7	6.8	-
KCl	-	6.8	10.2	13.7	20.5	27.3
Yeast	100	100	100	100	100	100
Water	900	900	900	900	900	900
Sugar	20	20	20	20	20	20
Bakery additive[3]	40	40	40	40	40	40

[1] All the amounts are given in gram.

[2] Control bread formulation. NaCl level was adjusted to be 1.5% (d.b.) on the baked bread based on Turkish Food Codex Regulation.

[3] Includes calcium carbonate, soybean flour, mono- and diacetyl tartaric acid esters of mono- and diglycerides, citric acid, ascorbic acid, and alpha amylase.

In the first stage, the sensory evaluation of the bread samples were carried out by 11 trained panellists (aged between 21 and 47 year, with 55% being female and 45% male). Panel members were selected from staff of the Department of Food Engineering, University of Mersin, Turkey. They have about 4 y of experience in sensory analysis of foods and consumed bread regularly every day. The panel was trained before the sensory evaluation according to the procedures given by Meilgaard *et al.* (2007). Sensory tests were carried out in a particular room with white paint walls, white lights (colour temperature = 3,000 K), controlled ventilation and away from the processing and sample preparation units. The temperature of the room was maintained at 25 °C. The panel members, abstained from eating, drinking or smoking for 1 h prior to testing, were asked to indicate the external appearance, internal pore structure, taste, saltiness, after-taste (after 3 min), general acceptability, and bitter/metallic flavour of the bread. A five-point scale, where 1 corresponded to extremely unpleasant, 5 extremely pleasant and 3 satisfactory, was used to quantify each attribute, except saltiness and bitter/metallic flavour. In the case of saltiness 1 corresponded to completely saltless taste, 5 extremely salty taste and 3 optimum/standard salty taste. For bitter/metallic flavour, on the other hand, 1 corresponded to barely perceptible, 5 extremely perceptible and 3 average perceptibility. The bread formulation with the highest KCl replacement level and statistically the same sensory attributes with the control bread were chosen from the results of the sensory evaluations given above. The chosen formulation was then used in the triangle test to compare against the two control samples.

The triangle test was carried out by 44 panellists (19 men, 25 women, from 21 to 43 year old) according to the procedures given by Meilgaard *et al.* (2007). Bread slices were presented in three different plates encoded with random 3-digit numbers. Random numbers were generated by using the research randomiser (www.randomizer.org). Two plates contained the control bread sample while the third one had the bread sample with the formulation chosen according to the results of the first stage of the sensory evaluation, as described above. The panellists were then asked to differentiate the distinct sample compared to the other two cases. The correct answers were counted and compared with the critical number of correct answers at the 95% of significant difference level to complete the triangle test (Roessler *et al.,* 1978).

Statistical analysis

All the textural and sensory evaluation data were presented as average ± standard deviation of the triplicate measurements. Single factor Analysis of Variance (ANOVA) at 95% confidence interval was used to detect the significant differences among the dough samples based on the NaCl replacement with KCl. Multiple comparisons of means were performed using Tukey HSD tests at a level of significance of P<0.05. The SPSS statistical software (Version 11.5, SPSS Inc., Chicago, IL, USA) was used for analysing the texture and sensory evaluation.

3. Results and discussion

Textural analysis of the dough

Extensibility and the resistance to extension

The extensibility was the length that a dough piece can be stretched before breaking while the resistance to extension was the amount of energy required to stretch the piece of dough. It was, in the literature, reported that the parameters obtained by using the Kieffer extensibility rig were significantly correlated with the Extensograph parameters (Grausgruber *et al.*, 2002; Ktenioudaki *et al.*, 2011; Mann *et al.*, 2005).

Table 2 shows the extensibility and the resistance to extension values obtained by the Kieffer extensibility rig for all the dough samples prepared by different combinations of NaCl and KCl. There was not a significant effect of KCl replacement level on the extensibility and resistance to extension (P>0.05) based on the results of the single factor ANOVA. Extensibility and the resistance to extension values obtained were also in the range of the values given by Fermin *et al.* (2005) and Wanga *et al.* (2003).

It is well known that salt increases the resistance to extension and extensibility of dough (Fisher *et al.*, 1949; Tanaka *et al.*, 1967). It helps controlling the dough texture by strengthening the gluten protein enabling to efficiently hold CO_2. Lynch *et al.* (2009) noted that the extensibility or resistance to extension of wheat dough was not affected by reducing NaCl levels from 1.2 to 0.6 or 0.3% (w/w). However, more than 20% reduction in resistance to extension and extensibility values was recorded when NaCl

Table 2. Textural analysis results for doughs as affected by sodium chloride replacement with potassium chloride.[1]

Replacement ratio (%)	Extensibility (mm)	Resistance to extension (g)	Stickiness (g)
0	15.3±2.0^{a}	23.3±2.3^{a,b}	73.7±2.4^{a}
25	15.1±1.9^{a}	25.2±2.0^{a}	68.6±6.4^{a}
37.5	14.8±1.6^{a}	21.7±2.6^{a,b}	68.4±3.4^{a}
50	15.6±1.1^{a}	25.4±2.5^{a}	75.0±2.4^{a}
75	14.2±1.1^{a}	20.5±2.9^{a,b}	72.0±6.6^{a}
100	14.5±2.0^{a}	17.8±0.6^{b}	72.0±3.8^{a}

[1] Values within a column followed by a common letter are not significantly different (P<0.05).

content reduced from 1.2 to 0%. In another study, Salovaara (1982b) indicated that decreasing the NaCl content from 2.0% (flour weight basis) to 1.2% and replacing it with KCl did not significantly affect the Extensograph properties of wheat dough. The similar effects of NaCl and KCl on dough extensibility and resistance to extension might again be explained by the similar chemical properties of Na and K in the Hofmeister series where the ion interaction to affect protein stability is explained (Baldwin, 1996).

Stickiness

Dough stickiness is primarily a function of the combination of surface and rheological properties (Dobraszczyk, 1997). Stickiness might cause major problems during processing where dough sticks to handling equipment leading to process disruption and product losses. NaCl addition is known to be one effective solution to prevent the sticky dough problems. Therefore, dough stickiness is an important parameter that should be monitored when NaCl replaced with KCl or another salt to reduce the Na content. Stickiness values for the dough samples prepared with different combination of NaCl and KCl are reported in Table 2. Results indicated that substitution of NaCl with KCl for the all combinations studied did not significantly affect the stickiness of dough even though there seemed to be a reduction in the stickiness values at the replacement levels of 25 and 37.5%, the single factor ANOVA results demonstrated that there was no significant difference based on the KCl replacement ratio ($P>0.05$). Chen and Hoseney (1995) indicated that the addition of excess water increases the stickiness of dough. The amount of water used in this study was comparatively lower than the conventional recipes. Therefore, this could be another reason why the dough is not becoming sticky when reducing NaCl. Additionally, the stickiness values obtained in this study were also similar to the results obtained by Chen and Hoseney (1995).

Sensory evaluation of wheat bread

Sensory evaluation scores are reported in Table 3. No significant differences in sensory scores was detected for the external appearance and internal pore structure of breads at all KCl replacement levels based on the single factor ANOVA results ($P>0.05$). In the cases of taste, after-taste, saltiness bitter taste/metallic flavour and general acceptability, there were still no significant differences between control bread group and the samples from the 25 and 37.5% replacement levels ($P>0.05$). However, for these attributes, sensory scores started decreasing as NaCl was replaced with KCl at 50% and higher levels ($P<0.05$). While saltiness scores of the sample wheat breads were similar up to 37.5% replacement level, the panellists detected metallic flavour/bitter taste for the formulations where KCl replacement with higher than 37.5%. Studies for the possibility to replace NaCl with KCl in various food products also gave same results where K-salts might give the perception of a bitter/metallic off-flavour (Braschi *et al.*, 2009; Desmond, 2006; Salovaara, 1982a). In a study conducted by Braschi *et al.* (2009), the bread samples where 50% of the NaCl replaced with KCl were judged to be acceptable overall, but had a poor flavour and after-taste. However, Takano and Kondou (2002) reported that the bread in which 75% NaCl was replaced with potassium gluconate was as acceptable as standard bread. However, 100% replacement of NaCl with KCl resulted with significant reduction in the salt taste. Wyatt (1983) indicated that 50% reduction of the sodium level for wheat

Table 3. Sensory analysis results for breads as affected by sodium chloride replacement with potassium chloride.[1]

Attribute[2]	Replacement level (%)					
	0[3]	25	37.5	50	75	100
External appearance	4.6±0.5[a]	4.1±0.9[a]	4.5±0.5[a]	4.6±0.5[a]	4.7± 0.5[a]	4.6± 0.5[a]
Internal pore structure	4.3±0.7[a]	3.7±0.9[a]	4.6±0.8[a]	4.0±0.8[a]	4.0±1.5[a]	3.6 ±0.8[a]
Taste	4.4±0.5[a]	4.1±0.6[a]	4.4±0.6[a]	3.0±1.0[b]	2.4±1.0[bc]	1.7±0.8[c]
After-taste	4.6±0.5[a]	4.3±0.8[a]	4.3±0.8[a]	3.1±1.1[b]	2.0±0.8[c]	1.3±0.5[c]
Saltiness	3.2±0.6[a]	3.1±0.4[a]	2.9±0.4[a]	2.6±0.5[ab]	2.7±0.9[ab]	2.1±0.7[b]
Bitter/metallic flavour	1.2±0.3[a]	1.3±0.5[a]	1.4±0.8[a]	3.4±1.3[b]	3.6±1.0[b]	4.6±0.5[c]
General acceptability	4.4±0.6[a]	3.9±0.4[a]	4.3±0.8[a]	3.0±0.8[b]	2.4±1.1[b]	1.6±0.5[c]

[1] Values within the same line followed by a common letter are not significantly different ($P<0.05$).
[2] For external appearance, internal pore structure, taste, after-taste, and general acceptability, 1 corresponded to 'extremely unpleasant', 5 to 'extremely pleasant' and 3 to 'satisfactory'. For saltiness, 1 corresponded to 'completely saltless', 5 to 'extremely salty' and 3 to 'optimum salt level'. For bitter/metallic flavour, 1 correspond to 'barely perceptible', 5 to 'extremely perceptible' and 3 for 'average perceptibility'.
[3] Control bread.

bread and 25% reduction for cottage cheese did not affect the consumer acceptability.

In the current study, 75% reduction in NaCl content was not detected by the panellists for saltiness. This may indicate that KCl assist in perceiving the salty taste. In the case of bitter/metallic flavour, it was barely perceptible for the formulations with lower than 50% replacement level (Table 3). On the other hand the perceptibility scores of the bitter/metallic flavour for bread samples from the replacement levels of 50, 75 and 100% were higher than the average. Bitter/metallic taste is one of the most important disadvantages of using KCl as a NaCl replacer (Desmond, 2006). However, there were some studies in the literature which indicates that the bitter/metallic taste can be reduced/removed by using different chemicals (McGregor, 2004).

The results of the sensory analysis above showed that bread with 37.5% replacement level, statistically had the similar sensory scores with the control bread in terms of external appearance, internal pore structure, taste, after-taste, general acceptability, saltiness, and bitter/metallic flavour (Table 3). The bread samples prepared according to this formulation was then used in a triangle test compared to the two control bread samples. Out of 44 untrained panellists, 31 panellists could not correctly distinguish the difference in the taste of the sample where 37.5% of NaCl was replaced by KCl. 13 correct answers were below the number of correct answers given by Roessler *et al.* (1978) at the 95% of significant difference level. Therefore, results of the triangle test indicated that the bread sample with 37.5% replacement level had statistically similar sensory properties as the control samples. With this level, NaCl level in wheat bread can be reduced from 1.5 to 0.94% without a significant difference in overall taste and saltiness. In a triangle test conducted by Salovaara (1982a), it was also shown that bread can be prepared with up to 24% reduction in Na without detection any difference from the full sodium control bread. With a similar sensory panel structure to the current study, Braschi *et al.* (2009) also concluded that a substantial reduction in Na could be achieved via the substitution of K in white bread.

4. Conclusions

Starting from July, 2012, NaCl amount of bread loaves in Turkey was reduced to 1.5% (d.b.) with an ultimate goal of 1% in near future. The replacement of NaCl in bread production might be a complex issue since NaCl use is accepted to be a process requirement and a sensory property for quality. Even though KCl replacement for NaCl reduction in processed foods is suggested in the literature, with the new legislation, replacement of Na by K might be a challenge due to the bitter taste and metallic flavour of KCl. Therefore, in this study, optimal replacement levels of NaCl with KCl, without significantly affecting textural properties of dough and final sensory quality of wheat bread, were assessed. The samples, where NaCl replaced by KCl up to 37.5%, were found to have statistically the same dough textural properties and final product sensory attributes compared to the control sample. These results indicated that NaCl levels in wheat bread could be reduced from 1.5 to 0.94% (resulting from 37.5% KCl replacement of NaCl) without a significant difference in overall taste and saltiness. Since a small reduction in Na-intake might prevent health related problems in the long run, this strategy might be a feasible way to lower Na-content in wheat bread loaves in an industrial scale production line. For this base, further research should focus for the effects of various NaCl and its substitutes on end-product quality, e.g. crumb-crust texture, staling rate, retrogradation besides dough rheology.

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