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Sodium chloride replacement by potassium chloride in bread: Determination of sensorial potassium threshold and effect on dough properties and breadmaking quality

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ABSTRACT
High sodium intakes represent an important risk factor for hypertension, cardiovascular diseases and kidney diseases. Even during the current COVID-19 pandemic, hypertension was related to higher mortality rate in patients with coronavirus. Thus, it is necessary to apply strategies to reduce or replace sodium content in food most widely consumed, like bread. This work aimed at determining the sensorial potassium threshold when potassium chloride is used as a sodium chloride replacer in bread formulation, and at analyzing the effects of such replacement on the properties of dough and on the technological and sensorial quality of bread. A decrease was observed in dough rheological properties with NaCl reduction in the formulation. Sensorial potassium threshold was determined and KCl was used in bread formulation as a NaCl replacement up to 0.92% of the regular salt content (2%) undetected by its characteristic taste. NaCl reduction resulted in bread with lower specific volume, higher firmness, faster staling and clearer crust. KCl bread showed similar technological to 2% NaCl bread. Finally, it was possible to replace 50% of NaCl with KCl without reducing quality and consumer acceptability.

1. Introduction

Salt is the most common source of sodium intake. Processed foods such as ready meals, pickled vegetables, processed meats like bacon, sausage, ham and salami, cheese, salty snack foods and instant noodles, among others, contain large amounts of salt; and staples such as bread are largely responsible for the amount of sodium in many people’s diet. It is well known that the current dietary sodium intake in several countries exceeds nutritional recommendations, causing a major public health concern (Riis et al., 2020; Zhang et al., 2021). Hence, the WHO has proposed halving the prevalent mean sodium intake of approximately 4 g/d. Despite major educational efforts by governmental and medical authorities, emerging evidence of general population surveyed in different countries suggests that during COVID-19 lockdown most people’s diets have become less healthy because a decrease in nutritional quality (Bracale and Vaccaro 2020; Marty et al., 2020). Lockdown and confinement measures implemented during the COVID-19 pandemic caused social anxiety and depressions, thus prompting changes in lifestyle, eating habits, food preferences and health risk (Zhang et al., 2021). Indeed, emerging evidence points to a major shift to consumption of high-sodium foods during the pandemic lockdowns in the population from different countries and cultures (Zhang et al., 2021). Additionally, the demand for bakery products such as bread, snacks and cookies, has increased in households (Marty et al., 2020).

It has been well established that high dietary sodium intake is strongly associated with major risk of cardiovascular diseases, hypertension, and kidney diseases (Riis et al., 2020). In addition, there is growing evidence that excessive sodium intake also affects the immune system within the gastrointestinal tract (Willebrand, 2018). It thus contributes to creating a pro-inflammatory microenvironment predisposing or aggravating potential cardiopulmonary complications in the increasing number of COVID-19 patients (Tzoulis et al., 2021).

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Nowadays, there has been increased interest in public health strategies to reduce sodium intake. One way to reduce salt consumption implies decreasing its content in those products highly demanded by consumers, such as bread, which represents approx. 30% of the overall sodium intake (Bolhuis et al., 2011). Nevertheless, salt reduction in bread is difficult to achieve due to its multifunctional performance in the breadmaking process and end product properties. Salt inhibits yeast activity and helps to control dough expansion; it strengthens the dough network, affects bread volume and crumb, prolongs shelf life and also influences taste and flavor (Mondal and Datta, 2008). Any attempt to reduce salt content in bread should maintain dough handling and consumer acceptance (Diler et al., 2016). There are many strategies that manufacturers can adopt to help consumers reduce their salt intake, including the reduction of salt particle size to give a faster perception of saltiness, sodium substitution by spices, herbs, blends, and other minerals such as potassium, magnesium and/or calcium. Potassium chloride (KCl) is the most common mineral salt used, showing similar properties to those of NaCl (Bassett et al., 2014). Increasing dietary potassium is recommended to the general population by USDA (USDA, 2010). In fact, adopting potassium enriched salts is dependent on several factors, including their effect on food taste, food conservation, food microstructure, and cost. Specifically, replacement of NaCl with KCl has resulted in undesirable bitter and metallic flavor. This modification in palatability alters consumer acceptance of end products (Antúnez et al., 2018). In wholemeal bread, a replacement of 55.2% of KCl was possible (Charlton et al., 2007). Braschi (2009) noted that 50% substitution of NaCl with KCl was sensory accepted but kept poor aftertaste and flavor. Although numerous studies have sought diverse strategies to reduce sodium in bread, it is still difficult to compare results as different formulations were applied, and the sensorial potassium threshold has been analyzed in few baked matrices such as toast (Antúnez et al., 2018) and brown bread (Charlton et al., 2007). In this context, the present work is aimed at determining the sensorial potassium threshold as a sodium replacement in bread formulation and at analyzing its effect on the properties of dough, as well as its technological and sensorial quality.

2. Materials and methods

2.1. Materials

Bread wheat flour without any added additives was supplied by a milling industry (José Minetti y Cía Ltda Saci, Córdoba, Argentina). Flour consisted of moisture (\% 12.98 ± 0.09, ash (\%), db 0.70 ± 0.01, protein (\%, db) 14.29 ± 0.02 and lipid (\%, db) 1.03 ± 0.01. Each content was determined according to AACC methods 44–15.02, 08–12.01, 46–12.01 and 30–25.01, respectively (AACC, 2010). Carbohydrates (71.0 ± 0.3%, db) were determined by differences from other components. The NaCl and KCl used were food-grade.

2.2. Methods

2.2.1. Rheology properties of dough

The rheological behavior of dough was determined by means of farinographic and alveographic assays. Farinographic tests (CW Braubender Instruments, Inc., Germany) were carried out according to the following proportions (2% NaCl; 1%NaCl; 0%NaCl; 1%NaCl:1%KCl, 2% KCl). Water absorption (WA), development time (DT) and stability (S) were determined. Alveographic tests (Chopin, France) were carried out on dough prepared with the same proportions of salt as mentioned above. The following parameters were determined: tenacity (P), extensibility (L), baking strength (W), ratio P/L. Both tests were performed in duplicate, and each parameter was expressed as mean ± standard deviation.

2.2.2. Differential scanning calorimetry

Starch gelatinization and retrogradation of bread dough were analyzed using a DSC823e Calorimeter (Mettler Toledo, Switzerland). Bread dough was prepared using 100% wheat flour, 59% water and 3% yeast; and proportions of salts previously mentioned. The ingredients were kneaded for 2.5 min with a Philips HR 1495 kneader (Philips, Argentina) and fermented 1 h at 30 °C and 80% relative humidity. Afterwards, the dough was degassed, laminated and hand-bowled. A small portion (30 mg ± 3 mg) was placed in a 100 µL capacity aluminum capsule. The sealed capsules were immediately tested. The dough samples were heated in the calorimeter following a temperature profile in order to simulate the temperature in the center of the crumb during bread baking (León et al., 1997). Temperature was maintained at 30 °C for 2 min and was then increased from 30 °C to 110 °C at 11.7 °C/min; the sample was finally kept at 110 °C for 5 min. The starting temperature, “onset” (To), peak temperature (Tp) and gelatinization temperature range (ΔTg), as well as starch gelatinization enthalpy (ΔHg) (expressed as mg J/mg dry sample), were obtained from each test. Subsequently, the gelatinized (“baked”) samples in the DSC capsules were left to cool and stored for 3 days at 25 °C. On the 1st and 3rd day of storage, the capsules were heated back into the calorimeter according to the following program: isotherm at 25 °C for 2 min, and heating from 25 to 120 °C at a speed of 10 °C/min. From the thermograms obtained, Tc, Tp, ΔT, and retrograde starch enthalpy (ΔH) (expressed as mJ/mg dry sample) were determined. The dough with the different proportions of salts was made in duplicate. In each dough, starch gelatinization parameters were determined in duplicate at each storage time. The results were expressed as average ± standard deviation.

2.2.3. Sensorial potassium threshold

The difference threshold is defined as the degree of change in stimulus needed to produce a detectable change in perception (Lawless et al., 1999). The sensorial potassium threshold test of bread was carried out according to method E 679-04, ASTM (1997) with ninety bread-usual-consumer volunteers, from different socioeconomic backgrounds; the volunteers were drawn from the staff Nacional University of Cordoba. To determine the difference threshold, the paired difference methodology, 2-AFC (Two Alternative Forced Choice), was applied, in which each panelist received a series of pairs of bread samples comprising a control sample (2% NaCl) and a problem sample, and they had to select the sample that showed greater bitter or metallic taste. In order to select the series of pairs of bread samples, the panelists started at the lowest concentration step, which should be two or three concentration steps below the estimated threshold. A constant factor of 0.875 was used to obtain KCl concentrations. This correction factor determined the reduction percentages of NaCl, starting with 2% of NaCl. The result of the first reduction was used to calculate the value of second reduction, and so on. By difference of the regular content of salt in bread (2%) and the percentage of NaCl determined with the factor for each reduction, the percentage of KCl to be used in each case was calculated. The bread-making process was carried out according to the method IRAM 15858-1:1996 and the formulation used was 100% wheat flour, 3% yeast, 59% water and the following salt reduction sequence: 1.75%:0.25%, 1.53%:0.47%, 1.34%:0.66%, 1.17%:0.83%, 1.03%:0.97%, 0.90%:1.10% (NaCl:KCl). The bread dough was placed in a mold and fermented 75 min at 30 °C and 98% relative moisture (RM). Finally, doughs were baked at 215 °C for 20 min. The loaves were then left for 1 h at room temperature to cool. The bread samples were cut into 1.5 cm slices and each slice was cut in turn into two portions, which corresponded to approximately 15 g of each sample.

The six plates containing each bread sample pair were presented upwards in KCl percentage, one at a time, as the evaluation of the previous pair concluded. The results were analyzed by a linear correlation between the percentage of correct responses and the logarithm of the concentration, as well as by logarithmic regression between the
proportion of correct responses and the concentration of KCl. The average concentration of the difference threshold was determined as the percentage of KCl corresponding to 75% of correct responses according to Lawless et al. (2010).

2.2.4. Bread-making procedure and technological quality

The bread-making process and formulation were the same as those used to make the sensory threshold potassium test (IRAM 15888-1:1996). To evaluate the reduction of NaCl, bread was made with 2%, 1% and 0% NaCl. To assess replacement with KCl, bread was prepared with NaCl:KCl mixtures in the following proportions: 1%:1% and 0%:2%.

After pre-fermentation, the dough was rolled in a Mi-Pan vroller (Mi-Pan, Córdoba, Argentina) with two 50.0 × 12.7 cm rollers and separated into 180 g pieces. Each dough sample was placed in molds and taken to the fermentation chamber for 75 min at 30 °C and 98% RH. Finally, the samples were baked at 215 °C for 20 min. Each baking test was performed in duplicate. The bread specific volume was determined by seed displacement and expressed by dividing bread volume by weight (cm³/g) (AACC, 2010).

Crumb bread firmness was evaluated at different times (2, 24 and 72 h) to determine the effect of storage time in thermally sealed poly bags at room temperature. At each time interval, two bread pieces were cut into two slices of 25 mm each, and the ends of the loaves were discarded. The initial firmness of the crumb (2 h after baking) was reported as the average concentration of the difference threshold was determined as the proportion of correct responses and the concentration of KCl. The percentage of KCl corresponding to 75% of correct responses according to Lawless et al. (2010).

2.2.6. Statistical analysis

An acceptability test of bread with NaCl replacement (50%) with KCl was conducted. Sensory potassium threshold detected by consumer panelists was taken into account.

The same bread-usual-consumer panel that participated in the potassium threshold detection test was also used for the acceptability test. Bread were evaluated on the basis of acceptance of their appearance, flavor taste, texture, and general acceptability on a nine-point hedonic scale. Results were expressed as L*, lightness; a*, red-greenness; b* yellow-blueness.

3. Results and discussion

3.1. Effect of NaCl reduction and replacement on dough rheological behavior

The study of rheological characteristics of the dough is important as it provides information on its behavior during the development process. The reduction of NaCl in the dough resulted in changes in farinographic parameters (Table 1). As noted in previous studies (McCann 2013), NaCl significantly reduced the ability of flour to absorb water and increased dough development time and stability. The effect of NaCl on the water absorption capacity of wheat flour is due to the competition of sodium and chloride ions with water molecules on the surface of proteins: ions interact with the lateral chains of proteins and hinder the absorption of water by flour (Beck et al., 2012). The dough bread had pH 6 and, in this condition, gluten proteins had positive charge; electrostatic repulsion occurred between them, causing proteins to hydrate quickly (Miller and Hoseney 2008). However, electrostatic repulsion kept protein chains away from each other, hindering interaction between gliadin and glutenin, resulting in a weaker dough.

NaCl neutralized protein charge, decreasing electrostatic repulsions and allowing protein chains to interact with each other. This caused a slow protein hydration and allowed them to form hydrophobic interactions and disulfide bridges, increasing the β-sheet structure between proteins (Welleber et al., 2003) and the formation of large fibrillar structures that lead to a stronger and more stable dough.

The total replacement of 2% NaCl with 2% KCl during dough elaboration led to no significant differences in water absorption and development time, which agrees with that reported by Chen (2018). Regarding dough stability, a decrease was observed when 2% KCl was used in the formulation (Table 1). However, although the decrease in stability was significant (p < 0.05), the value was slightly lower than that of NaCl dough and higher than that obtained when no salt was incorporated into the dough, which would indicate that it could be used as a NaCl replacement in bread formulation. In the presence of KCl, as with NaCl, a strong interaction is found between proteins, dough being more resistant to kneading.

A clear trend in dough extensibility was not observed (Table 1). Dough tenacity and baking strength decreased significantly with the decrease in NaCl content. These results also showed NaCl effect on the electrostatic and hydrophobic interactions, and on the formation of disulfide bridges of gluten proteins, increasing dough tenacity and values of parameter W.

The replacement of 50% of NaCl with KCl did not show a negative effect on these parameters, indicating that during dough fermentation they will have a similar behavior, and the quality of the bread will not probably decrease. When 2% KCl was used in dough formulation, increase values (p < 0.05) were observed in extensibility compared to 2% NaCl sample; however, P and W significantly decreased (p < 0.05) in relation to the samples in which 2% NaCl was incorporated.

### Table 1

| Samples | WA (%) | DT (min) | S (min) | P (mm) | L (mm) | W (10⁻¹ J) |
|---------|--------|----------|---------|--------|--------|------------|
| NaCl    | 62.8 ± 0.6 | 6.3 ± 0.1 | 47.5 ± 2.1 | 232.0 ± 7.1 | 14.5 ± 4.2 | 7.4 ± 4.0 |
| NaCl    | 53.8 ± 0.3 | 12.0 ± 0.1 | 16.8 ± 4.2 | 52.0 ± 1.4 | 52.0 ± 4.2 | 5.0 ± 4.0 |
| NaCl    | 59.7 ± 0.0 | 11.3 ± 0.1 | 13.7 ± 4.2 | 60.0 ± 1.4 | 52.0 ± 4.2 | 7.4 ± 4.0 |
| NaCl    | 58.9 ± 0.2 | 13.9 ± 0.1 | 18.3 ± 4.2 | 52.0 ± 1.4 | 52.0 ± 4.2 | 7.4 ± 4.0 |
| NaCl    | 58.2 ± 0.4 | 12.6 ± 0.1 | 16.4 ± 4.2 | 60.0 ± 1.4 | 52.0 ± 4.2 | 7.4 ± 4.0 |

WA, Water absorption; DT, development time; S, stability; P, tenacity; L, extensibility; W, baking strength.

Different letters in the same column indicate significant LSD-Fisher differences (p ≤ 0.05) among samples.
3.2. Effect of NaCl reduction and replacement on the thermal properties of bakery dough

Gelatinization and retrogradation of starch are important processes during bread making, influencing final characteristics and staling of bread. In addition, these parameters are affected by the other components present in the dough formulation. Table 2 shows the onset (T<sub>o</sub>) peak (T<sub>p</sub>), endset temperature (T<sub>e</sub>), temperature range (ΔT<sub>p</sub>) and gelatinization (ΔH<sub>g</sub>) and retrogradation (ΔH<sub>r</sub>) enthalpy of dough starch. It was found that the reduction of salt in bread dough decreased gelatinization temperature (T<sub>o</sub>) as well as T<sub>p</sub> and T<sub>e</sub> consistent with that observed by Chiotelli (2002) when assessing the effect of salt on starch gelatinization. The effect of NaCl on starch gelatinization has been associated, on the one hand, to the salt effect on the water system, and on the other hand, to electrostatic interactions between salt and starch hydroxyl groups (Wu et al., 2006). Chiotelli (2002) linked the higher gelatinization temperature of the dispersed starch in a NaCl solution to an increase in system viscosity, which slows the hydration and structural disorganization of starch granules.

When the amount of water was limited as in bread dough, gelatinization occurred more slowly, and two transition endotherms began to be observed: one glass transition concerning the amorphous phase (mainly the branching regions of the amylepectin and most amylose chains) and the fusion of crystallites (formed by adjacent short chains of amylepectin intertwined into double helices) (Maache-Rezzoug et al., 2008).

In the results obtained, a decrease in both ΔH<sub>g</sub> and ΔT<sub>p</sub> was observed as salt in the sample was reduced. Incorporating NaCl into the system decreased the water available for gelatinization, making most of the more stable crystals melt rather than gelatinize. This led to the unification of gelatinization endotherm with melting endotherm of more stable starch crystals, increasing the value of ΔH<sub>g</sub> and ΔT<sub>p</sub>. On the other hand, the onset temperature of gelatinization increased as NaCl was replaced with KCl. These results did not agree with those reported by Jane and Ames (1993), who showed that the increase in T<sub>p</sub> followed the same order as the increase in the load density of alkaline metal ions: LiCl > NaCl > KCl > RbCl. No significant differences in peak and endset gelatinization temperature were observed. On the other hand, a decrease in ΔH<sub>g</sub> and ΔT<sub>p</sub> was noted as NaCl was replaced with KCl. Possibly, NaCl had greater interaction with the water of the system, causing a greater number of stable crystals to melt.

When a sample bread was heated in the DSC capsule, a new endotherm was found, whose temperature peak was related to the temperature at which it melted the retrograded amylepectin, and the enthalpy change associated with that phase transition could be measured. DSC could be used to quantify the rate of staling because both melting endotherm of retrograde amylopectin and increase in crumb firmness, are similar in timeline magnitude (Ma et al., 2020). However, while the firmness measurement obtained from the texture profile analysis (TPA) depended on bread volume, the retrogradation of amylepectin did not seem to be related to this parameter (Gray et al., 2003). NaCl reduction significantly increased retrogradation enthalpy (ΔH<sub>r</sub>) after 1 day of storage. In addition, a longer storage time significantly increased ΔH<sub>g</sub> for each formulation (Table 2). Higher retrogradation enthalpy in samples without NaCl addition could indicate that this bread will have higher firmness during storage and higher firming rate compared to 2% NaCl samples. The replacement of 50% of NaCl with KCl slightly modified the retrogradation enthalpy, with significant differences observed only at day 1 of storage. Use of 2% KCl increased ΔH<sub>g</sub> to both day 1 and day 3 of storage, compared to 2% NaCl.

### Table 2

| Sample | ΔH<sub>g</sub> (J/g) | T<sub>o</sub> (°C) | T<sub>p</sub> (°C) | T<sub>e</sub> (°C) | ΔT<sub>p</sub> (°C) |
|--------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 2% NaCl | 1.66 ± 0.04<sup>a</sup> | 61.73 ± 0.46<sup>b</sup> | 72.90 ± 0.51<sup>b</sup> | 84.93 ± 0.64<sup>b</sup> | 23.51 ± 0.79<sup>b</sup> |
| 1% NaCl | 1.59 ± 0.04<sup>a</sup> | 61.56 ± 0.46<sup>b</sup> | 72.22 ± 0.51<sup>b</sup> | 82.68 ± 0.64<sup>b</sup> | 21.06 ± 0.79<sup>b</sup> |
| 0% NaCl | 1.44 ± 0.04<sup>a</sup> | 60.17 ± 0.46<sup>b</sup> | 70.83 ± 0.51<sup>b</sup> | 79.83 ± 0.64<sup>b</sup> | 19.60 ± 0.79<sup>b</sup> |
| NaCl:1% KCl | 0.12± 0.08<sup>bc</sup> | 62.44 ± 0.51<sup>bc</sup> | 73.46 ± 0.65<sup>bc</sup> | 85.46 ± 0.79<sup>bc</sup> | 23.03 ± 1.47<sup>bc</sup> |
| KCl | 2% | 1.05 ± 0.01<sup>a</sup> | 63.56 ± 0.46<sup>b</sup> | 72.96 ± 0.51<sup>b</sup> | 82.12 ± 0.64<sup>b</sup> | 18.57 ± 0.79<sup>b</sup> | 19.39 ± 0.79<sup>b</sup> | 2.00 ± 0.22<sup>b</sup> | 54.87 ± 0.51<sup>b</sup> | 56.06 ± 0.51<sup>b</sup> | 65.15 ± 0.51<sup>b</sup> | 72.80 ± 0.51<sup>b</sup> | 73.46 ± 0.51<sup>b</sup> | 79.83 ± 0.51<sup>b</sup> | 85.46 ± 0.51<sup>b</sup> | 23.03 ± 1.47<sup>bc</sup> | 18.57 ± 0.79<sup>b</sup> | 54.87 ± 0.51<sup>b</sup> | 56.06 ± 0.51<sup>b</sup> | 65.15 ± 0.51<sup>b</sup> | 72.80 ± 0.51<sup>b</sup> | 73.46 ± 0.51<sup>b</sup> | 79.83 ± 0.51<sup>b</sup> | 85.46 ± 0.51<sup>b</sup> | 23.03 ± 1.47<sup>bc</sup> | 18.57 ± 0.79<sup>b</sup> | 54.87 ± 0.51<sup>b</sup> | 56.06 ± 0.51<sup>b</sup> | 65.15 ± 0.51<sup>b</sup> | 72.80 ± 0.51<sup>b</sup> | 73.46 ± 0.51<sup>b</sup> | 79.83 ± 0.51<sup>b</sup> | 85.46 ± 0.51<sup>b</sup> | 23.03 ± 1.47<sup>bc</sup> | 18.57 ± 0.79<sup>b</sup> |

Table 3 shows the results corresponding to specific volume and psychical factors and the criterion used to produce a response. In order to determine the amount of NaCl that can be replaced by KCl in the formulation of bread without significant differences being detected with respect to bread with 2% NaCl, a threshold detection test was conducted. Thresholds are difficult to determine, as the ability to detect substances is influenced by psychological factors and the criterion used to produce a response.

The results of sensorial potassium threshold were analyzed by linear regression (R<sup>2</sup> = 0.8902) between the correct response percentage and the logarithm of KCl concentration (Fig. 1). From the line equation, the proportion equivalent to difference threshold was obtained as defined by the KCl percentage to 75% of correct responses, which corresponded to 0.92% of KCl. According to this result, the salt proportions to be incorporated into bread formulation from which KCl begins to be detected can be considered to be: 1.08:0.92 NaCl:KCl. KCl can be used in incorporation of bread formulation from which KCl begins to be detected by its characteristic taste.

3.4. Effect of NaCl reduction and replacement on bread quality

Braschi (2009) assessed the effect of KCl on the sensory characteristics of bread and found that, at high concentrations, it has an unpleasant taste, described as metallic or bitter. In order to determine the amount of NaCl that can be replaced by KCl in the formulation of bread without significant differences being detected with respect to bread with 2% NaCl, a threshold detection test was conducted. Thresholds are difficult to determine, as the ability to detect substances is influenced by psychological factors and the criterion used to produce a response. However, there is a range of concentrations below which substances are not detected under any circumstance and above which they can be detected (ASTM, 1997).

The results of sensorial potassium threshold were analyzed by linear regression (R<sup>2</sup> = 0.8902) between the correct response percentage and the logarithm of KCl concentration (Fig. 1). From the line equation, the proportion equivalent to difference threshold was obtained as defined by the KCl percentage to 75% of correct responses, which corresponded to 0.92% of KCl. According to this result, the salt proportions to be incorporated into bread formulation from which KCl begins to be detected can be considered to be: 1.08:0.92 NaCl:KCl. KCl can be used in bread formulation as a NaCl replacement up to 0.92% of the regular salt content (2%) undetected by its characteristic taste.
evaluated by the increase in crumb firmness over time. In the evolution of correct responses given by panelists and the logarithm of KCl concentration in bread formulation.

Table 3

| Formulation | SBV (cm³/g) | Initial Firmness (gf) | Firming Rate (gf/day) | L* | a* | b* |
|-------------|-------------|-----------------------|-----------------------|----|----|----|
| 2% NaCl     | 3.16 ± 0.03 | 533 ± 27<sup>a</sup> | 294 ± 18<sup>b</sup> | 66.2 | ± | ± |
|             |             | ± | ± | ± | ± | ± |
| 1% NaCl     | 3.17 ± 0.04 | 601 ± 69<sup>a</sup> | 445 ± 34<sup>b</sup> | 71.4 | ± | ± |
|             |             | ± | ± | ± | ± | ± |
| 0% NaCl     | 2.90 ± 0.05 | 717 ± 60<sup>a</sup> | 579 ± 45<sup>b</sup> | 72.2 | ± | ± |
|             |             | ± | ± | ± | ± | ± |
| 1% NaCl:1% KCl | 3.06 ± 0.11 | 531 ± 51<sup>a</sup> | 306 ± 22<sup>b</sup> | 67.1 | ± | ± |
|             |             | ± | ± | ± | ± | ± |
| 2% KCl      | 3.20 ± 0.04 | 466 ± 43<sup>a</sup> | 299 ± 15<sup>b</sup> | 64.7 | ± | ± |
|             |             | ± | ± | ± | ± | ± |

SBV, specific bread volume; L*, lightness; a*, red-greenness; b*, yellow-blue-ness. Different letters in the same column indicate significant LSD-Fisher differences (p ≤ 0.05) among samples.

initial firmness, crumb firming rate and crust color of the bread prepared by reduction of NaCl and replacement with KCl in the formulation. Bread made without NaCl had a significantly lower specific volume (p < 0.05) as compared to that made with NaCl. Similar results were reported by other authors (Miller and Hoseney, 2008; Beck et al., 2012). However, some studies found no variation in the value of the specific volume with the decrease in NaCl (Lynch et al., 2009). These differences may be attributed to the quality of the wheat flour used, more specifically, to its protein quality. Partial or total replacement of NaCl with KCl allowed obtaining bread with a specific volume like bread with 2% NaCl. In rheological tests, we observed that KCl significantly decreased protein interaction, possibly weakening the gluten network. However, this effect was not observed in the specific volume of the final product. Regarding the initial firmness of bread crumb, bread without sodium chloride had a higher initial firmness than that found in bread made with 2% NaCl and 1% NaCl.

On the other hand, a 50% reduction in NaCl allowed bread of similar quality to be obtained to bread made with 100% salt. No significant differences were found between the initial firmness of bread with a 50% replacement with KCl and with 2% NaCl. However, the initial firmness in bread with 2% KCl was lower than that for the other samples.

The bread staling is a complex phenomenon that decreases consumer acceptance and causes large economic loss. In general, the staling is evaluated by the increase in crumb firmness over time. In the evolution of crumb firmness, two mechanisms are accepted as valid, moisture loss from crumb to crust and recrystallization of amylopectin (Ribotta and Le Bail, 2007). Because amylose quickly retrogrades after bread cooling, it is considered to make little or no contribution to crumb firmness during storage (Ribotta and Le Bail, 2007). The firming rate of bread crumb elaborated without salt was significantly higher (p < 0.05) than that in the bread with NaCl or KCl (Table 3). The rate of starch retrogradation is directly proportional to moisture content. Salt, by decreasing water mobility, reduces the water rate of migration from the inner layer (crumb) to the outer layer (crust) of bread. This results in a more hydrated system that becomes stale at a lower rate when compared to systems in which salt is not present (Lynch et al., 2009). In addition, the firming rate of bread was not affected by the replacement of NaCl with KCl.

Finally, the crust color of bread was evaluated. It was observed that the reduction of NaCl increases luminosity and decreases a* and b* values (Table 3), yielding bread with lighter crust. The development of color in bread is the result of Maillard and caramelization reactions, influenced by water content, pH, amount of reducing sugars and amino acids (Hidalgo and Brando, 2011). During fermentation, yeasts convert carbohydrates from flour into CO₂ and ethanol. NaCl limits the metabolic activity of yeasts due to increased osmotic pressure of yeasts in the presence of salt, and due to the action of Na⁺ and Cl⁻ ions on the yeast membrane (Arino 2018). Excessive fermentation occurs in dough without salt, and possibly the lowest sugar content (as a result of increased yeast metabolism) is responsible for the decrease in Maillard and caramelization reactions resulting in bread with whiter crust. Replacing NaCl with KCl did not produce significant differences (p < 0.05) in lightness value and a* and b* parameters.

Results obtained showed that the use of KCl in the formulation of bread dough did not produce major changes in the main technological quality parameters of the final product, when compared to the use of 2% NaCl. Therefore, KCl can be used as a replacement.

3.5. Acceptability of bread elaborated with KCl

An acceptability test was carried out on a bread with 2% NaCl and bread sample with reduced sodium content to 50%, slightly higher than that detected by panelists in the sensorial potassium threshold test. Fig. 2 shows the results obtained from the sensorial analysis of bread. No significant differences were found in both appearance and texture. The samples were classified as “like slightly” in these parameters. Concerning taste and overall acceptability, higher qualifications were obtained for bread with 2% NaCl; yet the differences found were not statistically significant as compared to those made with NaCl. Similar results were reported by other authors (Miller and Hoseney, 2008; Beck et al., 2012). However, some studies found no variation in the value of the specific volume with the decrease in NaCl (Lynch et al., 2009). These differences may be attributed to the quality of the wheat flour used, more specifically, to its protein quality. Partial or total replacement of NaCl with KCl allowed obtaining bread with a specific volume like bread with 2% NaCl. In rheological tests, we observed that KCl significantly decreased protein interaction, possibly weakening the gluten network. However, this effect was not observed in the specific volume of the final product. Regarding the initial firmness of bread crumb, bread without sodium chloride had a higher initial firmness than that found in bread made with 2% NaCl and 1% NaCl.

On the other hand, a 50% reduction in NaCl allowed bread of similar quality to be obtained to bread made with 100% salt. No significant differences were found between the initial firmness of bread with a 50% replacement with KCl and with 2% NaCl. However, the initial firmness in bread with 2% KCl was lower than that for the other samples.

The bread staling is a complex phenomenon that decreases consumer acceptance and causes large economic loss. In general, the staling is evaluated by the increase in crumb firmness over time. In the evolution of crumb firmness, two mechanisms are accepted as valid, moisture loss from crumb to crust and recrystallization of amylopectin (Ribotta and Le Bail, 2007). Because amylose quickly retrogrades after bread cooling, it is considered to make little or no contribution to crumb firmness during storage (Ribotta and Le Bail, 2007). The firming rate of bread crumb elaborated without salt was significantly higher (p < 0.05) than that in the bread with NaCl or KCl (Table 3). The rate of starch retrogradation is directly proportional to moisture content. Salt, by decreasing water mobility, reduces the water rate of migration from the inner layer (crumb) to the outer layer (crust) of bread. This results in a more hydrated system that becomes stale at a lower rate when compared to systems in which salt is not present (Lynch et al., 2009). In addition, the firming rate of bread was not affected by the replacement of NaCl with KCl.

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Results obtained showed that the use of KCl in the formulation of bread dough did not produce major changes in the main technological quality parameters of the final product, when compared to the use of 2% NaCl. Therefore, KCl can be used as a replacement.
significant (p > 0.05). The taste was defined as “neither like nor dislike” in both formulations, and the overall acceptability was classified as “like slightly” in both types of bread.

There were no differences in consumer perception between bread elaborated with 2% NaCl and that in which a 50% salt replacement was carried out with KCl, when presented in a coded form. In addition, no significant negative effect was found to the quality of bread prepared with KCl, the use of this salt as a replacement for NaCl in bread can represent an interesting alternative for making reduced bread in sodium.

4. Conclusion

The negative effect in dough quality parameters caused by the reduction of NaCl in bread formulation could be counteracted by the replacement of salt with KCl improving dough tenacity and strength. In the same line, this study has demonstrated that partial replacement of NaCl by KCl in bread has less impact than reduction of NaCl on specific volume and crumb firming initially and on staling. On the other hand, KCl could be used in bread formulation as a NaCl replacement for up to 0.92% of the regular salt content (2%) and go undetected by its characteristic taste. And partial replacement of up to 50% NaCl by KCl without affecting consumer acceptance is feasible. Similar modifications made to the composition of popular processed foods that contribute a considerable amount of sodium to the diet might also be considered. Presently, this slight change in the worldwide dietary sodium-potassium ratio would advance towards the WHO goal of 30% reduction in global sodium intake by 2025 and would also help to effectively to lower the risks of prolonged and excessive sodium intakes in the vulnerable population.

Author contributions

Rodríguez De Marco Estefanía: Research. Navarro José Luis: Research and Writing. León Alberto Edel: Experimental designReviewing and Editing. Steffolani María Eugenia: Experimental design, Research, Conceptualization, Supervision, Formal Analysis, Writing- Reviewing and Editing.

Implication for gastronomy

Bread is one of the most consumed cereal-based staple food in a lot of people’s diets, but it is also a major contributor to sodium intake in many countries. So, reducing salt in bread formulations would help to reduce sodium consumption with health-related benefits. With the growing number of health-conscious consumers who aim to reduce their risk of chronic disease or to manage an existing condition, food manufacturers, bakers, restaurants, and also hospital catering services must adapt to the rheological properties of the dough and the technological quality of bread. In this way, KCl is an interesting strategy for gastronomy. Bakers, chefs’ restaurants, as well as those who make their bread at home, can consume a baked product with the same quality and sensorial characteristics as usual bread but with considerably less sodium content.

CRediT author statement

Rodríguez de Marco Estefanía: Conceptualization, Methodology.
Navarro José Luis: Writing- Original draft preparation. Steffolani María Eugenia: Conceptualization, Formal analysis, Writing - Review & Editing. León Alberto Edel: Writing - Review & Editing.

Declaration of competing interest

None

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