Effect of salt reduction on quality and acceptability of durum wheat bread

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Abstract

In the Mediterranean area, being pedoclimatic conditions more favorable to durum than common wheat cultivation, a bread-making tradition from durum wheat has been established. Durum wheat bread has a compact texture, with lower specific volume than common wheat bread. Due to health implications, several studies were carried out to reduce the content of NaCl in common wheat bread, however without considering durum wheat bread. The aim of this work was to assess the effect of salt reduction on quality and acceptability of durum wheat bread, with regard to specific volume, sensory features and aroma profile. Breads prepared with 5, 10, 15, 20 g/kg NaCl were submitted to consumer test. Control bread (20 g/kg salt) was the most appreciated, followed (>80% consumers) by bread with 10 g/kg salt, which showed a significantly (p<0.05) higher specific volume, but lighter crust and weaker aroma (lower amounts of Maillard reaction products and fusel alcohols).

Key words: bread; re-milled semolina; sodium chloride; rheofermentometer; volatile compounds

1. Introduction

Epidemiological studies suggest that, among other determinants, high dietary intake of salt (sodium chloride) contributes to hypertension which, in turn, is a major risk factor in the development of cardiovascular diseases (Bibbins-Domingo et al., 2010). The Committee on Medical Aspects of Food and Nutrition Policy (COMA) recommended a reduction of the dietary intake of salt from 9 g/day (3.6 g/day of sodium), recorded in the UK, to 6 g/day (Wyness, Butriss, & Stanner, 2012). This reduction was considered to be an achievable goal, rather than an optimal or ideal level of consumption. The World Health Organization and the Food and Agriculture Organisation recommended a daily salt intake of 5 g/day as a worldwide guideline (WHO & FAO, 2003).

In the 18th century, salt was needed primarily for food preservation and its usage in bread making was limited, never exceeding 10 g kg^{-1} (Quilez & Salas-Salvado, 2012). In the 20th century, the advent of systems to preserve foods other than salting, coupled with the industrialization and standardization of bread making, induced to raise the salt content of bread to 20 g kg^{-1}, as an easy way to improve flavor and reduce mould spoilage (Belz et al., 2012; Quilez & Salas-Salvado, 2012). Currently, the level of salt used in bread making is between 18 and 22 g kg^{-1}, therefore bread is considered one of the key contributors of dietary intake of salt, accounting for approximately 25% of total (Joossens, Sasaki, & Kesteloot, 1994).

Reporting sodium or salt content in the label of foods is now mandatory (European Parliament & Council of the European Union, 2011). According to the traffic-light labeling system, baked goods containing more than 15 g kg^{-1} of salt have a “red light” on the label, and those with 3-15 g kg^{-1} of salt a yellow one (Food Standard Agency, 2007). Therefore, lowering the salt intake by reformulating processed foods, including bread, has become a worldwide trend (Wyness et al., 2012). Nutrition claims such as “low sodium/salt”, “very low sodium/salt” and “sodium/salt-free” have also been ruled, which can be applied to foods containing 1.2, 0.4 and 0.05 g kg^{-1} of sodium, or the equivalent value for salt, respectively (European Parliament & Council of the European Union, 2006).

Numerous studies – see the reviews of Belz et al. (2012) and Silow, Alex, Zannini, & Arendt (2016) – have been carried out at the purpose of decreasing the salt content of bread prepared from common wheat flour (*Triticum aestivum* L.), assessing the lowest possible level in the range 13-17 g kg^{-1} (Conner, Booth, Clifton, & Griffiths, 1988; Girgis et al., 2003). Another strategy consisted in using salt replacers, i.e. magnesium and potassium salts, also complemented by taste enhancers. The replacers allowed maintaining better technological quality, but sensory limitations due to bitterness of the potassium salts were reported (Salovaara, 1982; Raffo et al., 2018). In brown bread, instead, the partial replacement of sodium chloride with potassium, magnesium and calcium salts was more acceptable (Charlton, Macgregor, Vorster, Levitt, & Steyn, 2007).

Salt concentration, however, is not only influential on the sensory acceptability of food in terms of taste. In case of bread, salt is an essential ingredient, being crucial for a proper development of dough structure. The interaction of salt with flour components such as gluten is very important to form a high quality bread crumb. Both too low and too high salt content in dough can be undesirable. Beck, Jekle, & Becker (2012a) observed that a dough prepared without salt showed significantly lower farinograph stability than a dough containing 10-20 g NaCl kg^{-1} wheat flour. No significant differences were observed within the range 10-20 g NaCl kg^{-1} wheat flour, whereas a further increase of farinograph stability was observed at levels of NaCl as high as 30-40 g kg^{-1} wheat flour. Preston (1989) reported that dough prepared with 0.05-0.10 M NaCl had higher dough strength than dough with no salt. Higher concentrations (0.5-1.0 M) of NaCl further increased dough strength, whereas in case of more chaotropic salts, such as NaI and NaSCN, it was observed a decrease. He, Roach, & Hoseney (1992) observed lower mixograph mixing time and peak height in the dough obtained with pure water than in a dough containing 15 g kg^{-1} NaCl, and recorded further significant increases at 40 g kg^{-1}. Similar results were reported by Danno & Hoseney (1982) in trials where NaCl was increased from 20 to 50 g kg^{-1}, although He, Roach, & Hoseney (1992) observed that flour of different baking quality (i.e. containing weak, average and strong gluten) responded differently to salt increase, with stronger flour showing greater dough strength increases. Salt has an influence also on fermentation rate, due to the effect of osmotic pressure on yeast growth. Absence of salt leads to excessive fermentation, causing gassy and acidic dough which, in turn, results in loaves with poor texture and an open grain. Amounts of salt higher than 2% result in a decrease of leavening ability, so that less sugars are metabolized, leading to darker crust during baking (Belz, Ryan, & Arendt, 2012).

In the Mediterranean area, pedoclimatic conditions are more favorable to durum wheat (*Triticum turgidum* subsp. *durum* (Desf.) Husnot) than common wheat cultivation. According to an ancient tradition, particularly consolidated in Southern Italy, bread is prepared from durum wheat re-milled semolina (Pasqualone, 2012), which has finer particle size (65-70% of particles below 180 μm), greater content of damaged starch and higher hydration rate than semolina for pasta-making, as well as higher tenacity to extensibility (P/L) alveograph ratio than common wheat flour (Giannone et al., 2018). Durum wheat bread has peculiar sensory features, compared to white bread prepared from common wheat. Bread crumb has a yellowish color, due to the presence of carotenoid pigments (Giannone et al., 2018). In addition, due to the typically high P/L ratio of the raw material used (Giannone et al., 2018), durum wheat bread is characterized by a compact texture – sometimes excessively close – with lower specific volume and harder crumb than white bread (Pasqualone et al., 2011). Some durum wheat breads, such as Altamura bread and Dittaino bread, have been awarded of the Protected Designation of Origin (PDO) mark for their high quality level and typicality (Pasqualone, Summo, Bilancia, & Caponio, 2007; Pasqualone, Alba, Mangini, Blanco, & Montemurro, 2010; Giannone et al., 2018).

Though the reduction of dietary intake of salt is highly recommended, and despite the large amount of studies in common wheat bread, no studies have been carried out so far to assess the effect of reducing salt content in bread prepared from durum wheat, which has gluten characteristics quite different from those of common wheat. Besides the positive effect on health, decreasing salt content could also moderate the compactness of durum wheat bread. The aim of this work was, therefore, to assess the effect of the reduction of salt content on quality and acceptability of durum wheat bread.

2. Materials and methods

2.1 Bread production

Bread-making trials were carried out using commercial re-milled semolina of durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) Husnot) provided by Molino Mininni, Altamura, Italy, which was obtained by blending different batches of wheat in the milling industry. The quality characteristics of re-milled semolina were the following: 12.8 g 100 g^{-1} protein; 11.7 g 100 g^{-1} dry gluten; 0.8 g 100 g^{-1} ash; 12.7 g 100 g^{-1} moisture; alveograph P/L ratio = 2.1; alveograph W = 203×10^{-4} J. All the values were within the usual range of variability for this commercial category (Pasqualone, Caponio, & Simeone, 2004; Giannone et al., 2018). Compressed fresh yeast (*Saccharomyces cerevisiae*, ‘Pinnacle’ yeast, AB Mauri, Casteggio, Italy) was provided by the local bakery where the bread-making trials were carried out (Panificio Bartolo Digesù, Bari, Italy). Food grade refined sea salt (99.5% NaCl, Piazzolla Sali, Margherita di Savoia, Italy) was purchased at a local retailer. Tap water used in the trials had hardness = 21 °f; conductivity at 20 °C = 441 µS/cm and dry residue at 180 °C = 308 mg L^{-1}. Bread rolls at four different salt (NaCl) levels were prepared according to Licciardello et al. (2017), with minor modifications. In detail, re-milled semolina was kneaded for 17 min at 25 °C by a diving arms kneader (Dell’Oro, Valmadrera, Lecco, Italy) with 10 g kg^{-1} compressed yeast, salt (5, 10, 15, or 20 g kg^{-1}), and water (595 g kg^{-1}). All amounts were on semolina weight basis. The amount of water was preliminary assessed through the farinograph test according to the AACC 54-21 method (AACC, 2000), to reach the farinograph consistency of 500 Brabender Units (Brabender instruments, Duisburg, Germany). Specifically, the amount of water needed in case of 5, 10, 15, and 20 g kg^{-1} salt accounted for 596, 596, 595 and 594 g kg^{-1} water, respectively. However, since the differences were very slight and not statistically significant, the average value (595 g kg^{-1} of water) was considered in all the trials for a simpler procedure, being the whole bread-making process done in a bakery and not in a laboratory. After kneading all the ingredients, the dough was rested in bulk for 1.5 h, then was manually scaled into 100 g pieces, rolled out, proofed for 90 min at 32 °C and 66% RH (Pavailler Engineering proofer, Galliate, Italy), and finally baked in an electric oven (RP, Rinaldi, Massa, Italy) at 240 °C for 20 min. Bread-making trials were repeated twice.

2.2 Rheofermentometer analysis of dough

The proofing properties of dough at different salt levels were assessed by the F3 rheofermentometer (Tripette et Renaud, Chopin Technologies, Villeneuve-la-Garenne, France). The analysis determines the total gas production of yeast and dough volume at standard barometric pressure over time. The method conforms to the AACC 89-01 (2000) standard for the measurement of yeast activity and gas production. An amount of 315 g of dough, prepared as described in paragraph 2.1, was submitted to the analysis according to the conditions of the Chopin protocol reported in the rheofermentometer instruction manual (Chopin Technologies, 2004), i.e. at 28.5 °C for 3 h, with a 2000 g weight. The instrument records two curves during dough fermentation and rising, one describing the development of the dough and another depicting the production and retention of gas. The following indices were measured: i) maximum dough height (H_m); ii) time needed to reach the maximum dough height (T_1); iii) dough height after 3 h (h); iv, v, vi) volume of gas produced (V_T), lost (V_L), and retained (V_R) at the end of the test (3 h); vii) gas retention coefficient (V_R/V_T). Analyses were carried out in triplicate.

2.3 Consumer test

A consumer test involving 65 habitual bread consumers (28 male and 32 female, enrolled among students and employees of University of Bari, Italy, aged from 21 to 60 y) was effected according to ISO 8587 (2006) to rank preference and assess willingness to purchase bread samples. Each consumer received: a white dish containing a square portion (4 cm side, 1 cm height) of each bread type (identified by an alphanumerical code); a glass of water; the evaluation sheet and a pencil. Each consumer had to taste the four bread types, with a break between each sample and cleansing the palate with water, then had to rank the samples according to preference from the most appreciated (score = 1), to the least appreciated (score = 4). The consumers were also asked to express their willingness to purchase each bread sample.

2.4 Determination of specific volume

The loaf volume of bread samples was determined by rapeseed displacement as in the AACC method 10-05.01 (2000). Bread specific volume was calculated as volume to weight ratio. Analyses were carried out in triplicate.

2.5 Color determinations

Crust color was analyzed by using the CR-300 Chromameter (Minolta, Osaka, Japan) under the illuminant D65 as in Giannone et al. (2018). Color parameters L^* (brightness), a^* (redness), and b^* (yellowness) were determined. Brown index was calculated as $100 - L^*$ (Giannone et al., 2018). Five replications were carried out for each determination.

2.6 Quantitative descriptive analysis (QDA) of sensory properties

Quantitative Descriptive Sensory Analysis of bread samples containing 10 and 20 g kg^{-1} salt was performed by a panel consisting of 8 trained members in the conditions described in a previous work (Pasqualone et al., 2007). Descriptors of taste (salty, sweet, and bitter), appearance (crust color), texture (crumb consistency and crumb grain), and odor (toasted, as perceived on crust, and yeasty, on crumb) were considered. The descriptors were rated on an anchored line scale that provided a 0-9 score range (0 = minimum; 9 = maximum intensity). The definitions of each descriptor and the scale anchors are reported in Pasqualone et al. (2007). Sensory sessions were carried out in triplicate.

2.7 Determination of volatile compounds

An amount of 0.50 ± 0.05 g of bread crust, cut in pieces of 2-3 mm, was submitted to the determination of volatile compounds by solid phase micro-extraction (SPME) coupled to gas-chromatography/mass spectrometry (GC/MS) as reported by Giannone et al. (2018) with minor modifications. In detail, the SPME analysis was made by using an Agilent 6850 gas-chromatograph equipped with an Agilent 5975 mass-spectrometer (Agilent Technologies Inc., Santa Clara, CA, USA) and with a HP-Innowax (Agilent Technologies Inc., Santa Clara, CA, USA) polar capillary column (60 m length × 0.25 mm i.d. × 0.25 µm film thickness), in the following conditions: SPME fiber size and material = 75 µm carboxen/polydimethylsiloxane (CAR/PDMS) (Supelco, Bellefonte, PA, USA); time and temperature of fiber exposure to sample headspace = 50 min at 35 °C; desorption time = 6 min; GC injector temperature = 280 °C; flow = 2.0 mL min^{-1}. The GC temperature program was set as follows: 35 °C for 8 min, increased by 5 °C/min to 50 °C (held for 5 min), increased by 5.5 °C/min to 230 °C (held for 5 min). The interface temperature was 230 °C. Mass spectra were recorded by electronic impact at 70 eV, in the mass range m/z 33–200. Peak identification was performed by computer matching with the reference mass spectra of National Institute of Standards and Technology (NIST) and Wiley libraries. The semi-quantitative data (peak areas expressed as total ion counts - TIC) were used to compare the samples, as in Giannone et al. (2018). The analysis was carried out in triplicate.

2.8 Statistical analyses

The data obtained were submitted to statistical analysis using XLStat software (Addinsoft, NY). Analysis of variance (ANOVA) followed by Tukey's HSD test was used to compare bread samples. The results of preference ranking test were analysed by the non-parametric Friedman test. Consumers' willingness to purchase was modelled by binary logistic regression.

3. Results and discussion

3.1 Effect on rheofermentometer indices of dough

The rheofermentometer was used to measure the development of durum wheat dough at different salt levels, during a 3-h fermentation. This method allows evaluating the fermentative capacity of flours, as well as yeast activity, by providing information on both gas production and ability of dough to retain the produced gas. As expected, the lowest dough development was observed at the highest salt level, due to inhibiting activity of salt on yeasts (Belz, Ryan, & Arendt, 2012). A progressively more pronounced development was observed as the salt content decreased (Table 1).

In detail, higher salt levels caused a decrease of the volume of CO_2 produced (V_T), which resulted in lowering both the gas production curve (H'_m) and the maximum height of dough (H_m). Besides, the increase of salt content prolonged the time needed for reaching the maximum dough height (T'_1), which was significantly longer in dough containing 20 g kg^{-1} salt than in the other, less salty, types of dough. Beck, Jekle & Becker (2012b) observed a similar increase of H_m in dough made of common wheat flour, when salt amounts were progressively lowered from 40 to 0 g kg^{-1}. However, in our salt content range, i.e. 5-20 g kg^{-1}, Beck et al. (2012b) registered H_m values accounting for 73-82 mm, which were higher than our results (accounting for 45-55 mm). Although the effect of different yeast activity and fermentative attitude of flour cannot be excluded, the observed difference in H_m was probably due to the high alveograph P/L ratio of re-milled semolina, which inhibited the dough to expand more freely. The presence of tenacious and little extensible gluten is quite common in re-milled semolina (Giannone et al., 2018; Pasqualone et al., 2011), also due to breeding programs for improving the pasta-making performances of durum wheat (De Vita et al., 2007).

While inhibiting fermentation, however, salt had a strengthening effect on gluten (Preston, 1989), therefore it helped to retain the gas produced. Due to its ionic nature, salt positively influences the interactions between gluten strands in the dough (Beck et al., 2012a). Therefore, at higher salt levels, longer time (T_x) was needed before that some gas was lost through the dough network (Table 1). As a consequence, at 20 g kg^{-1} salt level, the height of dough observed at the end of the rheofermentometer test (h) was very similar (only 6% decrease) to the maximum dough height recorded (H_m) in the whole trial. Lower amounts of salt, instead, caused a decrease of h by 24-35%. Finally, the gas retention coefficient (V_R/V_T) was slightly higher in presence of higher salt contents, but without significant differences with the other samples.

To sum up, due to an improvement of gluten network, the saltiest dough showed a more effective ability in retaining the gas released by fermentation, resulting in a low volume of lost gas (V_L). However, at the same time the saltiest dough produced the lowest volume of gas (V_T) and, as a consequence, it showed the lowest volume of retained gas (V_R) at the end of fermentation.

3.2 Effect on consumer appreciation

The mean appreciation scores of breads at decreasing salt levels are reported in Figure 1. The consumers were asked to rank bread samples according to their preference, from the most appreciated (score = 1) to the least appreciated (score = 4). Control bread (20 g kg^{-1}) was the most appreciated by consumers, but without significant differences with bread containing 15 g kg^{-1} salt. It would be therefore possible to decrease the salt amount of durum wheat bread formulation to 15 g kg^{-1} without significantly affecting consumers appreciation. Similarly, studies carried out in common wheat bread pointed out an optimal level of salt in the range 13-17 g kg^{-1} (Conner et al., 1988; Girgis et al., 2003).

Bread with 10 g kg^{-1} salt had an intermediate appreciation score, whereas bread with 5 g kg^{-1} salt was rejected by the majority of consumers. A non-linear relationship was observed (Fig. 1) between the mean ranking assigned to breads by consumers and their salt contents: these findings point out that a substantial reduction of salt results in a limited decrease of acceptability compared to bread prepared with 20 g kg^{-1} salt.

The consumers were also asked to express their willingness (P) to purchase each bread type. Binary logistic regression was used to analyze the responses. The obtained regression equation was the following:

$$P(purchase) = \frac{exp(Y')}{1 - exp(Y')}$$

where

$$Y' = -1.147 + 0.2624 \times NaCl\ (g\ kg^{-1})$$

All goodness-of-fit tests (Deviance, Pearson and Hosmer-Lemeshow) allowed to reject the *null* hypothesis for the obtained model. The curve of the probability to purchase bread as a function of salt content (Fig. 2) allows to estimate that more than 80% of consumers would purchase bread prepared with 10 g kg^{-1} salt. This kind of bread would contain half the salt content usually employed in bread-making, and even less than half the salt content used in Southern Italy (where the trials have been carried out), where the majority of bakers include 25 g kg^{-1} salt in bread formulation. Such a decrease would effectively contribute to lowering the sodium dietary intake. On the basis of the results of the consumer test, bread with 10 g kg^{-1} salt was submitted to further investigations, in comparison with control bread, to evaluate the effect of salt lowering on bread quality features other than taste.

3.3 Effect on bread quality characteristics

Specific volume is one of the most important quality characteristics of bread, related to crumb softness. Soft and well developed bread loaves show high specific volumes. The value of specific volume observed in bread prepared with 20 g kg^{-1} salt was low, indicating a very compact inner structure, typical of bread obtained exclusively from durum wheat re-milled semolina, without blending with common wheat flour (Giannone et al., 2018; Pasqualone et al., 2011) (Table 2). Lowering the salt content from 20 to 10 g kg^{-1}, a significant increase of specific volume was observed, essentially due to a positive effect on dough fermentation, as shown by rheofermentometer data. Similar results were observed by other authors who studied the effect of salt decrease in common wheat bread (Beck et al., 2012b). Specific volume of bread paralleled the trend observed in the rheofermentometer indices of dough development (H_m and H'_m), as well as in the volume of gas produced (V_T), and retained (V_R), during rheofermentometer test. Significant correlations between bread specific volume and rheofermentometer indices were reported by Beck et al. (2012b).

Brown, appealing crust is another appreciated characteristic of durum wheat bread. Bread with lower salt content showed a less colored crust. All colorimetric indices (a^*, b^* and $100-L^*$) significantly increased as salt level increased, due to a more intense Maillard browning (Moreau, Bindzus, & Hill, 2009; Silow et al., 2016). Several mechanisms have been proposed to explain the positive effect of salt on bread color, including the inhibition of fermentation, with consequent higher amounts of sugars left, prone to be involved in Maillard and caramelization reactions during baking (Belz et al., 2012).

Among the sensory features, the highest scores were attributed to crumb consistency and crust color. Bread prepared with 20 g kg^{-1} salt showed the typical sensory characteristics of durum wheat bread, with highly consistent crumb and brown crust (Giannone et al., 2018; Licciardello et al., 2017). The variation in salt content had a significant impact on the sensory profile: in addition to the expected effect on taste, with higher scores for “salty” and lower for “sweet” descriptor as the level of salt increased, significant differences were observed in texture and odor. In particular, paralleling the values of specific volume, bread with 10 g kg^{-1} salt showed a less consistent crumb than bread with 20 g kg^{-1} salt. Crumb grain of the least salty bread showed also a more open structure with larger pores, but the difference with the other bread type was not statistically significant.

The sensory evaluation of crust color, which was darker in bread containing 20 g kg^{-1} salt, agreed with the colorimeter data.

The odor descriptors “yeasty” and “toasted”, ascertained in crumb and crust, respectively, were significantly affected by salt variation, with higher score for yeasty and lower for toasted in bread with 10 g kg^{-1} salt than in the saltiest formulation. The increase of yeasty odor intensity as salt content decreased has been reported also in common wheat bread (Raffo et al., 2018).

Besides the effect of fermentation, which was more intense in reduced-salt bread as shown by rheofermentometer data, a flavor-enhancing effect of salt has been reported, probably due to the ability of salt in influencing water activity. The water restriction by salt results in the concentration of flavor molecules in solution and affects their volatility (Costa-Corredor, Serra, Arnau, & Gou, 2009). In addition, the increase of ionic strength, caused by the presence of salt, influences the chemical bonds within the food system and, therefore, the flavor sensation (Hutton, 2002).

3.4 Effect on bread volatile compounds

One of the most appreciated sensory characteristics of bread is its aroma, which depends on the combination of various factors: type of ingredients and yeast, extent of mechanical-enzymatic degradation due to kneading and leavening, and intensity of the thermal reactions occurring during baking. The SPME/GC-MS analysis of volatile compounds of crust allowed identifying several aroma compounds, including alcohols, aldehydes, ketones, carboxylic acids, lactones, furan compounds, and pyrazines (Table 3).

Strecker aldehydes (mainly 2-methylpropanal, 3-methylbutanal and 2-methylbutanal, deriving respectively from valine, leucine and isoleucine), 3-methyl-butanol, 2-furan-methanol (furfuryl alcohol), furfural, methylpyrazine, acetic acid and ethanol were the most abundant compounds in all samples.

Furans, together with pyrazines, pyrroles, and Strecker aldehydes, typically arise from thermal degradation of sugars and Maillard reaction, therefore are quite common in the aroma profile of bread crust or cookies (Giannone et al., 2018; Giarnetti et al., 2015). These compounds were detected in durum wheat bread in previous researches (Giannone et al., 2018; Licciardello et al., 2017). Other compounds, such as 3-methyl-butanol (isoamyl alcohol), 2-methyl-1-propanol (isobutyl alcohol), and 2-methylpropanoic acid derive from yeast metabolism (Hansen & Schieberle, 2005). Small amounts of sulfur compounds were also observed, such as carbon disulfide and dimethyl sulfide. The latter derived from the decomposition of methional, the Strecker aldehyde of methionine (Giannone et al., 2018).

A significant effect of salt level on the volatile profile was observed. Higher amounts of Strecker aldehydes, 2-methylfuran, methylpyrazine and diacetyl (2,3-butanedione) were detected in bread with 20 g kg^{-1} salt, due to more relevant Maillard browning associated to higher salt levels (Moreau et al., 2009), as confirmed by color determinations. Acetaldehyde and acetic acid, mainly deriving from fermentation, showed higher amounts in reduced-salt breads, in accordance with the increased fermentation rates. Fusel alcohols (2-methyl-1-propanol and 3-methyl-1-butanol), produced by yeasts either from amino acids through the Ehrlich pathway, or from carbohydrates during branched-chain amino acids synthesis (Watanabe, Fukuda, Asano, & Ohta, 1990) were unexpectedly detected in higher amounts in breads with 20 g kg^{-1} salt, probably due to environmental effects on the synthetic pathways of these compounds, already pointed out by transcriptomic studies. In particular, Schoondermark-Stolk et al. (2006) reported that at slightly acidic pH, as in the dough of the present study (data not shown), the production of 3-methyl-1-

butanol by *Saccharomyces cerevisiae* increased at higher salt contents (though at pH 3.0 the highest levels were observed in absence of salt).

Control bread also showed higher levels of hexanal, imputable to catalytic action of salt on lipid oxidation (Snirivasan & Xiong, 1996). Hexanal, in fact, takes origin from the oxidation of linoleic acid, which is present in the fatty fraction of semolina.

Overall, the differences observed in the volatile profile of bread crusts agreed with the sensory evaluation of crust odor descriptor “toasted”.

4. Conclusions

With the exception of bread prepared with 5 g salt per kg^{-1} of re-milled semolina, the quality changes observed in reduced-salt breads did not compromise either their acceptability or the willingness to purchase expressed by consumers. The modifications induced by salt reduction in durum wheat bread were similar to those reported in literature for common wheat bread, and were essentially attributable to an increased fermentative capacity. Specifically, a reduction of salt by 50% (from 20 to 10 g kg^{-1}), which would help fulfilling healthier dietary levels, negatively influenced aroma profile and color of bread, leading to a less intensely colored crust and a weaker toasted aroma, but had a positive effect on bread specific volume and crumb consistency.

The latter findings are of particular interest in the production of durum wheat bread, which is known for being very compact due to the high alveograph P/L ratio of re-milled semolina. In fact, the raise of specific volume and the decrease of crumb consistency might meet the expectative of those people used to softer products such as white bread, therefore increasing the number of potential consumers of durum wheat bread.

Further studies are underway for assessing the effects of salt reduction in bread obtained from tetraploid wheats other than durum, such as emmer wheat (*Triticum dicoccon* Schrank).

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Figure captions

Figure 1. Mean ranking of four durum wheat bread types, containing different salt (NaCl) amounts, according to the preference expressed by consumers. Rank = 1 corresponded to the maximum appreciation; rank = 4 corresponded to the minimum appreciation.

Different letters mean a significant difference at $p < 0.05$ according to Friedman non-parametric test.

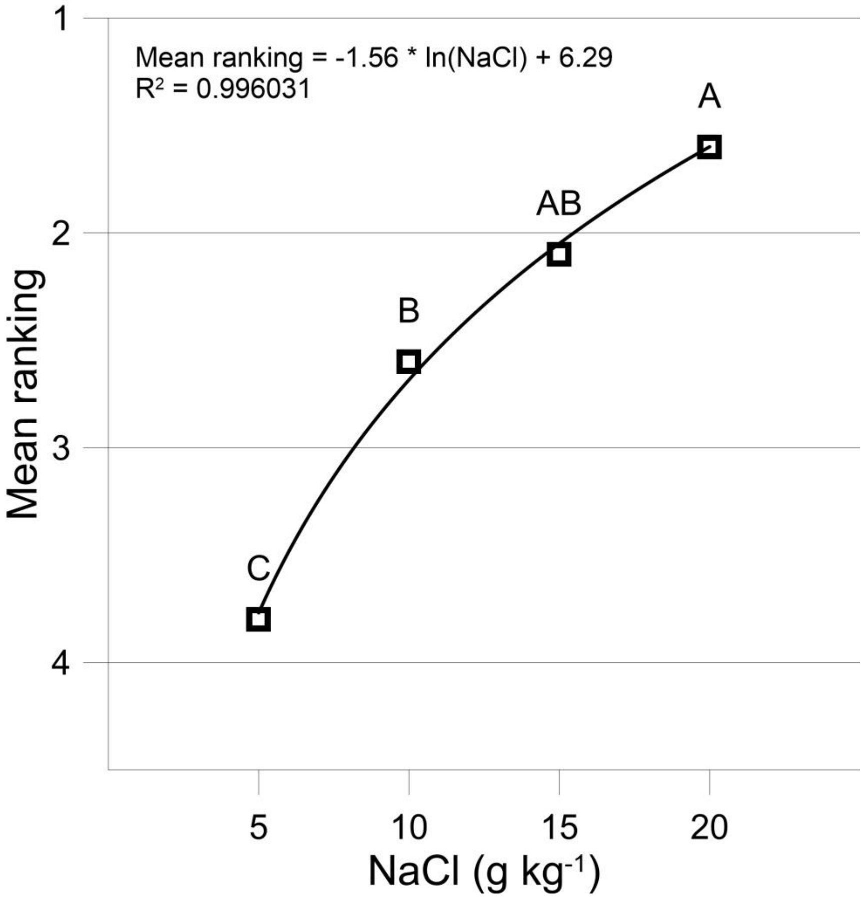

Figure 2. Curve describing the willingness to purchase bread as a function of salt content.

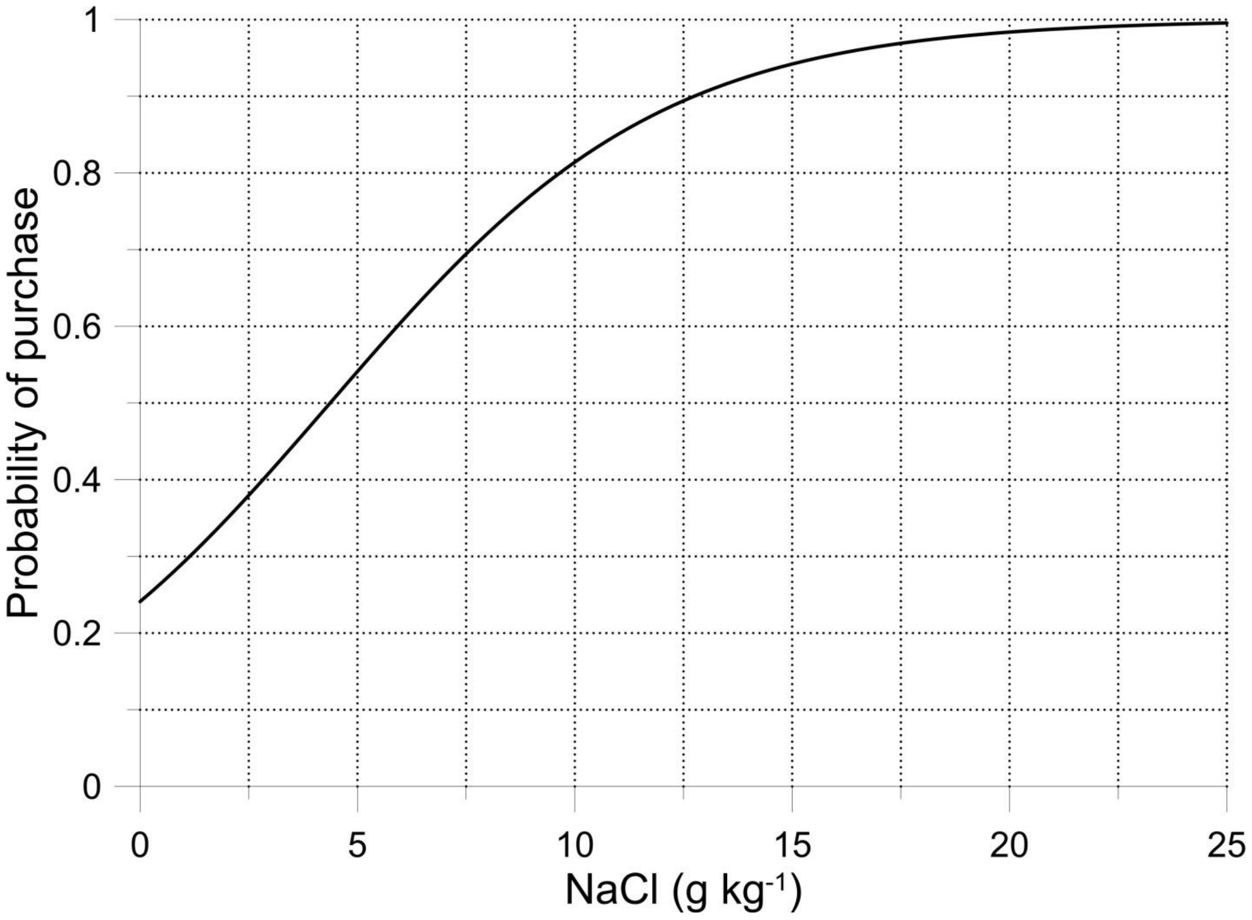

Table 1.

Mean and standard deviation of dough height and volume of gas produced and retained during fermentation, determined by rheofermentometer. Dough was prepared with re-milled durum wheat semolina at different salt (sodium chloride) levels.

Rheofermentometer parameter	**Salt level (g kg^{-1} re-milled semolina)**			
	5	**10**	**15**	**20**
Curve of dough development				
Maximum dough height (H_m) (mm)	55±1a	53±1a	49±1b	45±1c
Time to reach maximum dough height (T_1) (min)	88±2b	90±2b	90±2b	121±3a
Dough height after 3 h (h) (mm)	36±1b	37±1b	38±1b	42±1a
Decrease of dough height after 3 h compared to T_1 [$(H_m-h)/H_m$] (%)	35±2a	30±1a	24±1b	6±0c
Curve of gas production and retention				
Volume of gas produced (V_T) (mL)	1595±10a	1570±11b	1558±12b	1529±10c
Volume of gas lost (V_L) (mL)	359±4a	347±2b	339±4c	317±3d
Volume of gas retained (V_R) (mL)	1236±6a	1223±7ab	1219±8b	1212±7b
Gas retention coefficient [V_R/V_T] (%)	77±2a	78±2a	78±1a	79±2a
Maximum height of gas production curve (H'_m) (mm)	83±3a	79±2a	74±2b	69±1c
Time to reach maximum height of gas production curve (T'_1) (min)	45±1c	46±1c	51±2b	57±2a
Time needed to start losing gas (T_x) (min)	55±2c	58±2b	63±2a	64±2a

Different letters in row indicate a significant difference at $p < 0.05$.

Table 2.

Mean and standard deviation of specific volume, color indices and main sensory features of durum wheat bread at different salt (sodium chloride) levels.

Parameter	**Salt level (g kg^{-1} re-milled semolina)**	
	10	**20**
Specific volume (mL g^{-1})	3.61±0.18a	3.02±0.11b
Crust color indices		
Yellow index (b*)	24.55±0.36b	28.74±0.55a
Red index (a*)	4.01±0.17b	8.07±0.48a
Brown index (100-L*)	26.09±0.62b	33.27±0.81a
Sensory features		
Crumb grain	5.3±0.6a	4.2±0.5a
Crumb consistency	4.7±0.5b	6.1±0.6a
Crust color	4.5±0.4b	5.9±0.5a
Salty taste (crumb)	1.2±0.4b	2.8±0.4a
Sweet taste (crumb)	2.3±0.3a	1.5±0.2b
Bitter taste (crust)	0.5±0.2a	1.1±0.3a
Yeasty odor (crumb)	6.1±0.5a	4.9±0.4b
Toasted odor (crust)	2.5±0.3b	3.8±0.4a

Different letters in row indicate a significant difference at $p < 0.05$.

Table 3.

Volatile compounds (peak areas expressed as total ion chromatogram × 10^6) detected in the crust of durum wheat bread at different salt (sodium chloride) levels.

Compound	**Salt level (g kg^{-1} re-milled semolina)**				ANOVA (*p*-Value)
	10		**20**		
	Mean	SD	Mean	SD	
Alcohols					
Ethanol	1227.7	215.5	1150.2	159.1	n.s.
2-Methyl-1-propanol	59.6	15.5	132.2	34.0	0.01
3-Methyl-1-butanol	229.5	41.6	619.8	148.9	0.01
Aldehydes					
Acetaldehyde	39.5	8.5	19.7	2.5	0.01
2-Butenal	17.6	2.9	3.0	1.3	0.001
2-Methylpropanal	593.1	178.9	752.8	109.3	n.s.
2-Methylbutanal	104.2	21.9	331.5	89.4	0.01
3-Methylbutanal	353.4	187.1	1025.6	383.0	0.05
Hexanal	0.0	0.0	7.3	1.2	0.001
Ketones					
2-Propanone-1-hydroxy	208.6	17.2	142.1	10.6	0.001
Butanone	27.8	9.8	43.1	11.7	n.s.
2-Butanone-3-hydroxy	123.0	65.1	201.4	44.9	n.s
2,3-Butanedione	169.7	47.0	253.9	47.9	0.05
2,3-Pentanedione	21.2	7.3	59.9	31.3	n.s.
Carboxylic acids					
Acetic acid	208.8	31.3	164.0	17.8	0.05
Propanoic acid	29.3	3.9	32.1	5.7	n.s.
2-Methylpropanoic acid	32.5	10.1	117.5	19.5	0.001
2,2-Dimethylpropanoic acid	44.0	5.3	34.3	22.4	n.s.
Esters					
Ethyl-acetate	13.9	13.0	19.4	5.5	n.s.
Lactones					
γ-Butyrolactone	18.3	4.7	13.8	6.2	n.s.
Furan compounds					
Furan	15.7	4.9	12.3	2.3	n.s.
2-Methylfuran	8.2	10.2	24.0	7.6	0.05
2-Furanmethanol	449.6	109.9	337.0	46.5	n.s.
Furfural	291.6	70.1	224.8	12.0	n.s.
Pyrazines					
Pyrazine	78.4	26.9	61.6	11.9	n.s.
Methylpyrazine	156.9	72.0	279.2	58.8	0.05
Ethyilpyrazine	47.2	18.9	60.2	26.8	n.s.
2,3-Dimethylpyrazine	10.0	1.5	10.7	4.1	n.s.
Pyrroles					
Pyrrole	53.3	14.8	49.5	4.6	n.s.
1-Methyl-1-H-pyrrole	12.7	6.8	12.8	4.5	n.s.
Sulfur compounds					
Carbon disulfide	0.9	0.3	1.3	0.2	n.s.
Dimethyl sulfide	2.0	0.6	2.3	0.8	n.s.