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The Effect of Sea Salt with Low Sodium Content on Dough Rheological Properties and Bread Quality

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Abstract: The aim of this study was to analyze the effects of the addition of sea salt with low sodium content (SS) in a refined wheat flour at the levels of 0.3%, 0.6%, 0.9% 1.2% and 1.5% on the rheological properties of the dough during mixing, extension, pasting and fermentation and the bread quality in terms of bread physical properties, crumb and crust color, texture and sensory characteristics. According to the data we obtained, the SS presented a strengthening effect on the dough network by increasing its stability, dough development time, energy and resistance. Moreover, the SS addition resulted in an increase in dough extensibility, to a delay of the gelatinization process and an increase of the falling number value. The bakery products obtained with the SS were of a higher quality compared to the control sample, presenting better physical and textural characteristics, a darker color and being more appreciated by consumers with the increased level of SS addition in the wheat flour. According to the sodium content from the bread recipe, the bread samples obtained may be classified as products with a very low sodium content of up to a 0.6% SS addition in the wheat flour or with a low sodium content if at least 0.9% SS is contained in the bread recipe.

Keywords: sea salt; rheological behavior; bread making; bread quality; sodium content

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1. Introduction

The World Health Organization (WHO) promotes and encourages the food industry to reduce the salt (sodium chloride, NaCl) content in foods to achieve a maximum salt intake of 5 g per day for adults [1]. Worldwide, one-third of all deaths are due to cardiovascular diseases such as heart attacks and strokes. High blood pressure, a major risk factor for these diseases, is directly related to high daily sodium intake. Many consumers are unaware that more than 70% of salt consumption comes from processed foods, which are a major component of many diets, which may explain why many consumers are not concerned about excessive salt (sodium) in their diets [2–4]. Cardiovascular diseases are the leading cause of death in the world, with Europe alone estimated to have more than four million deaths each year, accounting for almost half of all deaths [5]. However, it seems that no European country meets the WHO recommended level for salt consumption (≤5 g/day); therefore, a salt reduction strategy of 16% is currently being applied over 4 years to reach a sodium chloride intake of less than 5 g per day by 2025 [6,7]. Although consumers are now becoming aware of the negative health effects of excess salt, they do not have much information about the link between salt and sodium, sodium intake in processed foods and recommended consumption. In developed countries, consumer awareness of proper nutrition and nutritionally healthy behavior increases with increasing education. Unfortunately, in middle- and low-income countries, this correlation does not apply, so regardless of the level of education they have access to, awareness of the negative effect of excessive sodium consumption on health is low [8]. Since salt (sodium chloride) is one of the four main ingredients that are used in bread making, and bread is one of the most consumed foods in the world nowadays, people are trying to find solutions to reduce its salt content [9,10]. Studies have shown that the addition of sodium chloride has an important effect on the development of the structure of gluten, on the fermentation process of the dough and the level of water activity in bakery products [11]. The addition of salt increases dough strength, presumably by affecting the distribution of charges on the protein. Salt anions in a dough system reduce the repulsion between the protein chains, favoring their interaction due to the fact that they can bind with the positive charges on the gluten proteins [12]. It affects dough rheological properties because it generates an additional conductivity due to the ion migration. According to Fanari et al. [13], salt addition has increased compliance values of the dough samples by having a negative effect on dough deformability and, as a consequence, it had an increased effect on dough strength. However, it seems that this effect is only when salt addition is in a concentration higher than 0.5%. Despite this, when salt addition in wheat flour was higher than 1.5%, it reduced dough elasticity and machinability stiffening of it in a significant way [12]. Still, it seems that salt's effect on dough mixing depends on the flour variety. For example, some studies reported a decrease of the storage (G′) and loss modulus (G″) [14], while others reported an increase of their values when salt was added in wheat flour [15]. Salt also has a controlling effect on fermentation, affecting the color of the crumbs and crust. Bread made without salt has a bland and unacceptable taste. However, it is very important not to use too much salt, as it masks the flavors created by fermentation and the addition of other ingredients. In addition to its contribution to taste, sodium plays an important role in bread acceptability by consumers [16]. In the absence of the addition of sodium chloride in a bread recipe, the activity of yeast is stimulated. This leads to a significant increase in the height of the dough, which cannot hold the gas that is formed very well, leading to products with low volume and porosity [17]. Moreover, the shelf life of the bread decreased, the crust became light-colored, the flavor was reduced and the taste became more of yeast. Although there are different methods reported for sodium chloride replacement or reduction in bread recipes, there are some difficulties, especially due to the salty taste produced by it [3,5,18]. The most used methods to reduce sodium chloride in bread making are by its substitution with other salts such as potassium chloride, magnesium salts and calcium salts, which are effective due to the fact that these salts may have a similar effect as sodium chloride on dough rheology and therefore on bread quality [3,6,19]. The aim of this study was to replace the sodium chloride with sea salt with low sodium content (SS), which is a combination between different chloride salts, namely sodium, potassium and magnesium, and to evaluate its impact on dough rheology and bread quality. This type of sodium chloride substitution may be useful in order to reduce the sodium content from bread in order to comply with World Health Organization recommendations and consumer demands. A few different studies related to the effect of sea salt on dough rheology and bread making have been previously made. However, to our knowledge, none of the previously reported studies were similar to our study. This is due to a multitude of factors. First of all, a wide variety of sea salt may exist with several chloride salt contents and sometimes different compounds that may contribute to the bread flavor [20]. Moreover, different combinations between sea salt and different ingredients that may improve bread sensory characteristics have also been studied [21,22], but their combined effects on dough rheology and bread quality were very different than those obtained with a single type of ingredient addition to wheat flour. Moreover, the studies previously made had also reported the effect of sea salt on dough behavior or bread quality in a limited way. For example, Arena et al. [23] reported the effect of low-sodium sea salt containing approximately 65% NaCl, 30% KCl, 1% $MgSO_4$ and 0.5% $CaSO_4$ only on durum wheat bread quality. Miller and Jeong [2] reported the effect of different commercial sea salts with high (48% sodium), medium (21.5% sodium) and low sodium contents (17.8% sodium) on dough rheology and bread quality (only consumer acceptance test). Simsek and Martinez [9] analyzed the effect of sea salt, of which the composition was not mentioned, on dough mixing, extension and bread quality (with no sensory analysis). Our study completes the previous studies made in a more complex manner, analyzing the effect of a sea salt with a low sodium content as sodium chloride (max. 7%) and other types of chloride salts ($MgCl_2$ and KCl) on dough rheological behavior during all bread-making processes (mixing, extension, pasting and fermentation) and bread quality (physical, textural, color parameters and sensory characteristics). It can offer a solution for bread producers to obtain bakery products of a good quality with a reduced sodium content that may have an important effect on daily sodium intake.

2. Materials and Methods

2.1. Materials

Refined wheat flour (harvest 2019) of 650 type provided by S.C. Mopan S.A. (Suceava, Romania) was used. The sea salt with low sodium content (SS) obtained from the Dead Sea was used. The sea salt presented the following composition: sodium as sodium chloride (max. 7%), magnesium chloride (31 ÷ 35%), potassium chloride (21 ÷ 27%) and water insoluble max. 0.1%. The wheat flour used in this study was analyzed for the following characteristics according to the Romanian and international standard methods: ash content according to ICC 104/1, moisture content according to ICC 110/1, protein content according to ICC 105/2, falling number according to ICC 107/1, wet gluten according to ICC106/1 and gluten deformation index according to SR 90:2007 [24,25]. The wheat flour data obtained were: 0.65 g/100 g ash content, 14.0 g/100 g moisture content, 12.67 g/100 g protein content, 442 s falling number value, 30 g/100 g wet gluten content and 6 mm gluten deformation value.

2.2. Dough Rheological Properties during Mixing and Extension

In order to analyze dough rheological properties during mixing and extension, a farinograph, 300 g capacity (Brabender, Duigsburg, Germany), and an extensograph (Brabender, Duigsburg, Germany) were used according to ICC methods 115/1 and 114/1, respectively [24]. The mixing values analyzed were water absorption (WA), dough stability (ST), dough development time (DDT) and degree of softening after 10 min (DS). The extension values analyzed were resistance to extension (R50), extensibility (Ext), maximum resistance to extension (Rmax), extensograph ratio number (R/E) at a proving time of 135 min and energy.

2.3. Dough Viscometric Rheological Properties

Dough viscometric rheological properties were analyzed using the amylograph (Brabender OGH, Duigsburg, Germany) and the Falling Number (Perten Instruments AB, Hägersten, Sweden) devices according to ICC methods 126/1 and 107/1, respectively [24]. The following parameters were determined: gelatinization temperature (T_g), temperature at peak viscosity (T_{max}), peak viscosity (PV_{max}) and falling number value.

2.4. Dough Rheological Properties during Fermentation

Dough rheological properties during fermentation were determined by using the rheofermentometer (Chopin Rheo, type F3, Villeneuve-La-Garenne Cedex, France) device according to the American Association of Cereal Chemists (AACC) method 89-01.01 [26]. The following parameters were determined: maximum level of gas production (H'm), volume of gas retained in the dough at the end of the test (VR), total volume of CO_2 production (VT) and retention coefficient (CR).

2.5. Bread Making

Bread samples were made by using as raw materials refined wheat flour of 650 type, sodium sea salt with low sodium content, deionized water according to the water absorption value and compressed yeast of Saccharomyces cerevisiae type in a level of 3% reported to the wheat flour used. The sea salt with low sodium content (SS) was added to the bread recipe in the following levels: 0.0% (control sample), 0.3% (SS_0.3), 0.6% (SS_0.6), 0.9% (SS_0.9), 1.2% (SS_1.2) and 1.5% (SS_1.5). All ingredients were mixed in a laboratory mixer

(Kitchen Aid, ARTISAN 4.8 L Tilt-Head Stand Mixer 5KSM175PS Whirlpool Corporation, Tulsa, OK, USA) at a low speed for 15 min until the dough presented elastic properties, began to detach from the wall of the mixing vat, the moisture from its surface disappeared and the surface of the dough became smooth and dry. After the dough was mixed, it was then divided, shaped and fermented in a leavening chamber (PL2008, Piron, Cadoneghe, Padova, Italy) for 40 min at 30 °C and 85% relative humidity. The dough was baked in an oven (Caboto PF8004D, Cadoneghe, Padova, Italy) for 50 min at 180 °C.

2.6. Bread Samples Analysis

2.6.1. Physical, Color, Texture Profile Analysis, Sensory Evaluation of Bread Samples

The bread's physical characteristics such as specific volume, elasticity and porosity were determined according to SR 91: 2007 methods [27]. Color characteristics L^*, a^* and b^* of crumb and crust of the bread were determined using a CR-700 colorimeter (Konica Minolta, Tokyo, Japan). Textural parameters such as gumminess, firmness, chewiness, elasticity and cohesiveness were determined using the TVT-6700 texture analyzer (Perten Instruments, Hägersten, Sweden). Sensory evaluation of the bread samples was performed using a nine-point hedonic scale by a panel of thirty semi-trained judges. The acceptance test was carried out with students from Stefan cel Mare University, who were screening based on their sensory acuity according to ISO 3972, ISO8586-1 and ISO8586-2 of the sensory laboratory of the Faculty of Food Engineering in an individual panel [28–30]. Bread samples were served at a temperature of approximately 20 °C (room temperature) in black dishes with dimensions of 10 cm × 3 cm. Every sample was labelled with random 3-digit codes. The bread appearance was evaluated for bread samples cut in half. The bread's sensory characteristics that were evaluated were appearance, color, flavor, texture, taste, smell and overall acceptability using a 9-point hedonic scale with the following meaning: 1 represents dislike extremely, 2 represents dislike very much, 3 represents dislike, 4 represents dislike slightly, 5 represent neither like nor dislike, 6 represents like slightly, 7 represents like, 8 represents like very much and 9 represents like extremely. Evaluators cleaned their mouths with water between every bread sample analysis, and no information was given to the evaluators about bread samples.

2.6.2. Sodium Analysis of Bread Samples

Chemical composition analysis of bread samples was carried out by atomic absorption spectroscopy (AAS) method, according to SR EN 14082:2003: 10 g ± 10 mg of sample was weighed in the crucible, the samples were calcined starting with the temperature of 100 °C, then the temperature was raised by 50 °C/hour up to 450 °C. The samples were kept overnight at 450 °C. Ash digestion was performed with concentrated HCl (6 mol/L). Evaporation of the acid was performed on the electric hob, and the residue was dissolved with 10 mL of HNO_3 (0.1 mol/L). The samples were diluted with deionized water. The absorbance of samples was measured by atomic absorption spectroscopy (AAS)-AA-6300-Shimadzu (Shimadzu Corporation, Kyoto, Japan) in order to determine the sodium concentrations. In order to achieve the calibration curve, solutions with 0, 1, 2, 3, 4, 5 and 6 mg Na/L stock solution were used. The atomization of the elements present in the samples was performed by a C_2H_2 flame; subsequently, the atoms interacting with the specific light of the element were provided by a hollow cathode lamp (Na, 589 nm). The analysis method of samples was configured to measure each sample five times, then to average three of them.

2.7. Statistical Analysis

Statistical software XLSTAT (free trial version, Addinsoft, NY, USA) was used for data processing. Data were expressed in triplicate as mean ± standard deviation. In order to evaluate the differences between means of the data, the one-way ANOVA was applied using Tukey's test at a 5% significance level. At $p < 0.05$, p values were considered statistically significant differences.

3. Results

3.1. Dough Rheological Properties during Mixing and Extension

The dough rheological mixing properties were shown in Table 1. As can be seen, the addition of the SS gradually decreased the water absorption and the degree of softening after 10 min by up to 6.9% and 26.3% for the sample with the highest level of SS addition in wheat flour compared to the control one. It can be seen that the development time and the dough stability increased with the increased level of SS addition in the wheat flour. For the samples with 1.5% SS addition, the ST values have been doubled, whereas for the DT this value has significantly increased ($p < 0.05$) up to 42.1%.

Table 1. Farinograph parameters of the dough samples with different levels of sea salt with low sodium content (SS) additions.

Dough Samples	WA (%)	DT (min)	ST (min)	DS (UB)
Control	60.5 ± 0.2 ^{a}	1.9 ± 0.1 ^{bc}	2.00 ± 0.1 ^{e}	76 ± 3.2 ^{a}
SS_0.3	59.5 ± 0.1 ^{b}	2.0 ± 0.05 ^{c}	2.9 ± 0.1 ^{e}	68 ± 0.5 ^{b}
SS_0.6	59.0 ± 0.1 ^{bc}	2.2 ± 0.05 ^{abc}	3.2 ± 0.1 ^{cd}	66 ± 1.5 ^{b}
SS_0.9	58.4 ± 0.2 ^{c}	2.4 ± 0.1 ^{ab}	3.5 ± 0.05 ^{bc}	62 ± 2.5 ^{bc}
SS_1.2	57.2 ± 0.1 ^{d}	2.5 ± 0.2 ^{a}	3.7 ± 0.05 ^{b}	60 ± 0.5 ^{cd}
SS_1.5	56.3 ± 0.2 ^{e}	2.7 ± 0.05 ^{a}	4.2 ± 0.1 ^{a}	56 ± 1.5 ^{d}

WA: water absorption; DT: development time; ST: dough stability; DS: degree of softening after 10 min. The results are the mean ± standard deviation ($n = 3$). Dough samples contain sea salt with low sodium content (SS). $^{a–e}$: mean values in the same column followed by different letters are significantly different ($p < 0.05$).

All dough rheological properties during extension increased with the increased level of the SS addition in the wheat flour, as can be seen from Table 2. Therefore, the highest values for dough rheological properties during extension were recorded for the sample with a 1.5% SS addition in the wheat flour of which all rheological values significantly increased ($p < 0.05$) up to 24.77% for R_{50}, up to 28.69% for Ext, up to 27.87% for Rmax and up to 66.66% for E compared to the control sample.

Table 2. Extensograph parameters at the proving time of 135 min of the dough samples with different levels of sea salt with low sodium content (SS) additions.

Dough Samples	R_{50} (BU)	Ext (mm)	R_{max} (BU)	E (cm^2)
Control	327 ± 2.3 ^{f}	115 ± 1.3 ^{e}	226 ± 2.1 ^{e}	57 ± 1.0 ^{f}
SS_0.3	346 ± 1.5 ^{e}	122 ± 2.5 ^{d}	231 ± 1.5 ^{e}	66 ± 1.0 ^{e}
SS_0.6	352 ± 2.1 ^{d}	128 ± 1.0 ^{cd}	245 ± 1.5 ^{d}	75 ± 1.5 ^{d}
SS_0.9	374 ± 1.5 ^{c}	132 ± 1.4 ^{bc}	254 ± 2.1 ^{c}	81 ± 1.0 ^{c}
SS_1.2	397 ± 1.5 ^{b}	137 ± 1.0 ^{b}	277 ± 1.0 ^{b}	88 ± 1.0 ^{b}
SS_1.5	408 ± 0.7 ^{a}	148 ± 1.0 ^{a}	289 ± 1.0 ^{a}	95 ± 0.7 ^{a}

R_{50}: resistance to extension up to 50 mm; Ext: extensibility; R_{max}: maximum resistance; E: energy. The results are the mean ± standard deviation ($n = 3$). Dough samples contain sea salt with low sodium content (SS). $^{a–f}$: mean values in the same column followed by different letters are significantly different ($p < 0.05$).

3.2. Dough Viscometric Rheological Properties

The effects of the addition of SS in the wheat flour on the rheological properties of viscosity are presented in Table 3. A significant increase ($p < 0.05$) of the gelatinization temperature (T_g) up to 2.4% and of the maximum viscosity (PV_{max}) up to 12% was observed with the increased level of the SS addition in the wheat flour. Moreover, a significant increase ($p < 0.05$) of the temperature at maximum viscosity (T_{max}) up to 1.4% was observed for the sample with an addition level of 1.5% SS in the wheat flour compared to the control one. The falling number value also increased by 10.24% for the sample with the highest level of SS addition in the wheat flour compared with the control one.

Table 3. Viscometric rheological properties of the dough samples with different levels of sea salt with low sodium content (SS) additions.

Dough Samples	Tg (°C)	PV_{max} (BU)	T_{max} (°C)	FN (s)
Control	62.3 ± 0.12 [b]	1081 ± 4.7 [f]	88.4 ± 0.18 [c]	322 ± 2.0 [a]
SS_0.3	63.3 ± 0.15 [a]	1092 ± 2.5 [e]	88.7 ± 0.05 [bc]	328 ± 1.5 [b]
SS_0.6	63.4 ± 0.05 [a]	1107 ± 3.5 [d]	89.0 ± 0.15 [abc]	342 ± 1.0 [c]
SS_0.9	63.4 ± 0.15 [a]	1153 ± 1.5 [c]	89.2 ± 0.15 [abc]	349 ± 1.0 [d]
SS_1.2	63.6 ± 0.12 [a]	1198 ± 2.0 [a]	89.4 ± 0.20 [ab]	352 ± 1.5 [de]
SS_1.5	63.8 ± 0.15 [a]	1211 ± 2.0 [b]	89.7 ± 0.05 [a]	355 ± 1.0 [e]

T_g: gelatinization temperature; PV_{max}: peak viscosity; T_{max}: temperature at peak viscosity; FN: falling number value. The results are the mean ± standard deviation (n = 3). Dough samples contain sea salt with low sodium content (SS). [a–f]: mean values in the same column followed by different letters are significantly different ($p < 0.05$).

3.3. Dough Rheological Properties during Fermentation

Dough rheological properties during fermentation are shown in Table 4. As can be seen, the values obtained on the rheofermentometer device showed that the maximum height of gas production (H'm), the total volume of CO_2 produced during fermentation (VT) and the volume of gas retained in the dough at the end of the test (VR) increased significantly ($p < 0.05$) with the increased level of SS addition in the wheat flour up to 0.6%, whereas at high levels they decreased. The retention coefficient decreased with the increased level of SS addition in the wheat flour.

Table 4. Rheological properties during fermentation of the dough samples with different levels of sea salt with low sodium content (SS) additions.

Dough Samples	H'm (mm)	VT (mL)	VR (mL)	CR (%)
Control	67.3 ± 1.8 [e]	1287 ± 8.3 [e]	1066 ± 7.3 [e]	82.8 ± 1.3 [a]
SS_0.3	82.7 ± 1.1 [c]	1551 ± 6.8 [c]	1272 ± 6.1 [a]	82.0 ± 1.4 [a]
SS_0.6	89.3 ± 1.2 [a]	1694 ± 4.1 [a]	1290 ± 4.2 [b]	76.1 ± 1.2 [c]
SS_0.9	85.1 ± 1.2 [b]	1631 ± 5.1 [b]	1238 ± 3.4 [c]	75.9 ± 1.1 [c]
SS_1.2	78.6 ± 1.5 [d]	1557 ± 5.5 [c]	1169 ± 3.5 [d]	75.0 ± 1.1 [b]
SS_1.5	78.0 ± 1.5 [d]	1506 ± 4.5 [d]	1043 ± 3.4 [e]	69.2 ± 1.4 [c]

H'm: maximum height of gaseous production; VT: total volume of CO_2 produced during fermentation; VR: volume of the gas retained in the dough at the end of the test; CR: retention coefficient. The results are the mean ± standard deviation (n = 3). Dough samples contain sea salt with low sodium content (SS). [a–e]: mean values in the same column followed by different letters are significantly different ($p < 0.05$).

3.4. Physical Characteristics of the Bread Samples

As can be seen from Table 5, significant differences ($p < 0.05$) were obtained between the control sample and bread samples with different levels of SS addition in the wheat flour. Moreover, the physical characteristics for the bread sample with a 1.5% sodium chloride addition (CS_1.5) had been determined. The highest physical characteristics were obtained for bread samples with a 0.6% SS addition in the wheat flour. However, when high levels of SS were added in the bread recipe, the bread physical characteristics began to decrease. This decrease is in agreement with the results reported by Arena et al. [23], who concluded that salts inhibit the activity of yeast, which leads to a decrease in CO_2 production and therefore to the bread's physical characteristics. The bread sample with a 1.5% sodium chloride addition in the wheat flour presented a significant ($p < 0.05$) lower specific volume compared to the bread samples with a sea salt addition in the bread recipe. However, this physical characteristic was higher than those obtained for the control sample with no salt addition in the wheat flour. The elasticity values were very close to those of the control sample, whereas the porosity did not present significant ($p < 0.05$) differences to the values obtained for the samples with a 0.9 and 1.2% sea salt addition in the wheat flour.

Table 5. Physical characteristics of the bread samples with different levels of sea salt with low sodium content (SS) additions.

Bread Samples	Specific Volume (cm^3/100 g)	Porosity (%)	Elasticity (%)
Control	325.25 ± 0.42 [a]	63.53 ± 0.31 [a]	95.08 ± 0.32 [ab]
SS_0.3	347.54 ± 0.86 [d]	69.30 ± 0.27 [d]	96.33 ± 0.23 [d]
SS_0.6	349.12 ± 0.12 [e]	72.67 ± 0.31 [e]	97.66 ± 0.21 [e]
SS_0.9	340.43 ± 0.64 [c]	68.09 ± 0.42 [c]	96.18 ± 0.32 [d]
SS_1.2	339.52 ± 1.03 [c]	67.99 ± 0.22 [c]	95.78 ± 0.42 [c]
SS_1.5	347.54 ± 0.86 [d]	66.97 ± 0.18 [b]	95.46 ± 0.23 [bc]
CS_1.5	332.97 ± 1.20 [b]	67.88 ± 0.12 [c]	95.00 ± 0.15 [a]

The results are the mean ± standard deviation (n = 3). Bread samples contain sea salt with low sodium content, SS and 1.5% sodium chloride (CS_1.5). [a–e]: mean values in the same column followed by different letters are significantly different ($p < 0.05$).

From the point of view of the color of the crumbs, it can be seen from the Table 6 that the samples with SS addition in the wheat flour have lower brightness (L^* value), yellow (b^* value) and a higher tint of red (a^* value) compared to the control sample. From the point of view of the color of the bread crust, it can be seen that the samples with the addition of SS have the same color parameters tendency as in the case of the breadcrumbs with the increased level of SS addition in the wheat flour. According to the color data obtained, it can be concluded that the bread samples become darker by adding SS in the bread recipe compared to the control sample.

Table 6. Color parameters of the bread samples with different levels of sea salt with low sodium content (SS) additions.

Bread Samples	Crust Color			Crumb Color		
	L^*	a^*	b^*	L^*	a^*	b^*
Control	69.48 ± 0.32 [a]	−4.40 ± 0.22 [ab]	19.58 ± 0.27 [a]	74.94 ± 0.41 [a]	2.97 ± 0.11 [c]	36.81 ± 0.27 [b]
SS_0.3	68.34 ± 0.51 [d]	−4.32 ± 0.14 [b]	19.32 ± 0.32 [b]	73.65 ± 0.71 [b]	3.34 ± 0.21 [b]	25.55 ± 0.42 [a]
SS_0.6	66.05 ± 0.24 [c]	−4.21 ± 0.22 [b]	18.94 ± 0.41 [c]	72.78 ± 0.37 [c]	3.52 ± 0.14 [f]	24.83 ± 0.31 [b]
SS_0.9	65.65 ± 0.72 [b]	−3.99 ± 0.12 [ab]	18.36 ± 0.27 [d]	71.09 ± 0.18 [d]	3.78 ± 0.31 [d]	22.99 ± 0.34 [c]
SS_1.2	64.34 ± 0.58 [e]	−3.97 ± 0.31 [a]	18.32 ± 0.42 [d]	69.49 ± 0.71 [e]	3.97 ± 0.22 [a]	22.47 ± 0.22 [d]
SS_1.5	63.55 ± 0.92 [f]	−3.92 ± 0.42 [a]	17.67 ± 0.11 [e]	68.03 ± 0.31 [f]	4.22 ± 0.11 [e]	22.11 ± 0.22 [d]

The results are the mean ± standard deviation (n = 10). Bread samples contain sea salt with low sodium content (SS). [a–f]: mean values in the same column followed by different letters are significantly different ($p < 0.05$).

The firmness and gumminess textural parameters of the bread samples decreased up to a level of 0.9% SS addition in the wheat flour, after which these values increased as it may be seen from the Table 7. The cohesiveness and resilience parameters decreased with the increased level of SS addition in the wheat flour up to 35.93% and 35.07%, respectively, for the bread sample with the highest level of SS addition in the wheat flour compared to the control one.

As can be seen from Figure 1, from a sensory point of view, in general the sample with the addition of 1.5% SS in the wheat flour was the most appreciated. It received the maximum score for overall acceptability, flavor, taste and smell. However, for color and texture characteristics, the sample with 1.2% SS addition in the wheat flour was the most appreciated, whereas for appearance the sample with 0.6% SS in the bread recipe received the maximum score value.

Table 7. Texture parameters of the bread samples with different levels of sea salt with low sodium content (SS) additions.

Bread Samples	Firmness (*N*)	Gumminess (*N*)	Cohesiveness (Adimensional)	Resilience (Adimensional)
Control	23.83 ± 0.16 [a]	15.29 ± 0.11 [a]	0.64 ± 0.01 [ab]	1.34 ± 0.02 [b]
SS_0.3	18.33 ± 0.32 [b]	11.08 ± 0.21 [b]	0.65 ± 0.01 [ab]	1.32 ± 0.01 [b]
SS_0.6	18.24 ± 0.22 [b]	10.29 ± 0.32 [c]	0.56 ± 0.01 [b]	1.14 ± 0.02 [c]
SS_0.9	14.31 ± 0.56 [c]	9.21 ± 0.37 [d]	0.52 ± 0.01 [a]	1.07 ± 0.03 [a]
SS_1.2	21.08 ± 0.22 [a]	14.31 ± 0.16 [c]	0.49 ± 0.02 [c]	0.99 ± 0.02 [d]
SS_1.5	21.47 ± 0.11 [a]	14.90 ± 0.21 [a]	0.41 ± 0.01 [d]	0.87 ± 0.02 [e]

The results are the mean ± standard deviation (n = 3). Bread samples contain sea salt with low sodium content (SS). [a–e] mean values in the same column followed by different letters are significantly different ($p < 0.05$).

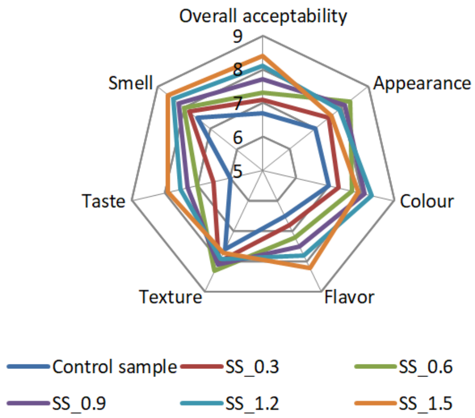

Figure 1. Sensory characteristics of the bread samples.

3.5. Sodium Content of the Bread Samples

The sodium content of the bread samples with sea salt addition in the wheat flour is shown in Table 8. As can be seen, the sodium value increased with the increased level of SS addition in the wheat flour. This increase is a significant one ($p < 0.05$) of ten times more for the sample with a 1.5% addition in the wheat flour compared to the control one.

Table 8. Sodium content of the bread samples with different levels of sea salt with low sodium content (SS) additions.

Bread Samples	Na (mg/100 g)
Control	8.14 ± 0.2 [f]
SS_0.3	23.22 ± 0.1 [e]
SS_0.6	38.35 ± 0.1 [d]
SS_0.9	53.75 ± 0.07 [c]
SS_1.2	67.25 ± 0.1 [b]
SS_1.5	82.5 ± 0.1 [a]

The results are the mean ± standard deviation (n = 3). Bread samples contain sea salt with low sodium content (SS). [a–f] mean values in the same column followed by different letters are significantly different ($p < 0.05$).

4. Discussion

Dough rheological properties with different levels of SS addition in the wheat flour provide information about dough behavior during mixing, extension, pasting and fermentation underlining the technological impact of SS on bread making. The SS addition decreased the water absorption (WA) value in agreement with the results reported by others [21,22]. This decrease is due to sea salt's ionic nature, which favors a higher association between gluten proteins as a consequence of their hydrophobic interactions, which increased by SS addition in the wheat flour. This leads to a decrease of the water-uptake ability of the wheat flour and therefore to the farinograph water absorption value. The SS addition in the wheat flour has a strength effect on wheat flour dough by increasing its stability (ST) and dough development time (DT) and by decreasing the degree of softening after 10 min (DS). This effect is due to a more compact gluten in the SS presence that may be attributed to the higher aggregation between gluten proteins, which presents almost 40% hydrophobic amino acids in their structure [31]. Our results are in agreement with other studies that have been reported by different research [31–33]. All the extensograph values increased with the increased level of SS addition in the wheat flour. These data also confirm the strengthening effect that SS has on wheat dough. SS increases dough resistance and energy, meaning that higher forces are necessary to stretch it. However, SS addition also increases dough extensibility. This may be due to the fact that SS ions affect the protein hydration from the dough system, competing for water with them. The fact that SS cannot hold water during all dough preparation periods may lead to an increase of free water amount from the dough system, causing an increase of its extensibility during proofing time. Similar data have also been reported by previous studies when different types of salts were added in the dough recipe [19,21,22,34,35]. During pasting, SS increases all the amylograph values and the falling number index. According to Nogueira et al. [36], the increase of the dough peak viscosity may be due to the suppression of the enzymatic activity in the SS presence. Another explanation is that SS may affect starch granule behavior, which remains intact before being broken down for a longer period of time. Moreover, the gelatinization temperature and temperature at peak viscosity increase with the increased level of SS addition in the wheat flour, indicating a delay of starch gelatinization and of dough maximum viscosity. The increase of dough viscosity is directly connected with falling number values, which are proportionally increasing with the increase of dough viscosity [37]. According to our data, SS addition in the wheat flour leads to an increase of dough viscosity and consequently to an increase of falling number values, these results being in agreement with those reported in other studies [21,22,38]. During fermentation, the maximum height of gaseous production (H'm), total carbon dioxide production (VT) and volume of the gas retained at the end of the test (VR) increased up to a level of 0.6% SS addition in the wheat flour, after which these values decreased. These behaviors are due to the yeast activity, which ferments the carbohydrates present in the dough system and also affects the dough's capability to retain the gas formed during the fermentation process. The yeast activity is expressed through the carbon dioxide released, which increases the H'm, VT and VR values. A higher value of these parameters indicates a more intense fermentation process by yeast of the fermentable sugars present in the wheat flour dough [39]. However, when high levels of SS are present in the wheat dough, the yeast activity is inhibited, probably due to the plasmolysis action of the yeast cells. Higher levels of SS addition in the wheat flour will induce an osmotic pressure on the yeast cells, which will lead to a decrease of the yeast activity and therefore of the H'm, VT and VR values [22]. The retention coefficient is related to VT and VR values being the ratio between VR and VT. A slight decrease of this parameter with the increased level of SS addition in the wheat flour, even when VT and VR are increased up to a 0.6% SS addition in wheat flour, indicates that the VR increase is lower than the VT one in the dough system. The data obtained by us were similar to those reported by others, who also concluded that higher levels of chloride salt addition in a wheat flour may lead to a decrease of the rheofermentometer values [19,21,22,40,41].

Bread's physical characteristics were improved up to a 0.6% SS addition in the wheat flour, after which these values decreased. However, these values were higher than those recorded for the control sample, which indicates the fact that for all bread samples that SS addition in the wheat flour improved bread quality. This improvement was a predictable one since SS addition increased the gas formed and dough height during the fermentation process, as the rheofermentometer data indicated. These data were in agreement with other studies that also reported an improvement of bread physical characteristics by chloride salts addition in wheat flour [17,23,41]. Moreover, compared to the bread sample with the 1.5% sodium chloride addition in the wheat flour, the samples with SS addition in the bread recipe presented higher values for bread physical characteristics, meaning that these samples were of a better quality. The sea salt is a mix of different chloride salts such as magnesium, potassium and sodium ones. According to Tuhumury et al. [34], the effects of KCl are very similar to those of NaCl on dough behavior due to its closeness in the Hofmeister series. However, the magnesium chloride, which represent 31 ÷ 35% from the sea salt that was in the highest level from the chloride salts, may cause a soluble effect on gluten proteins because they are situated in the destabilizing zone of the Hofmeister series. It can destabilize folded proteins, weakening the dough system [42]. On dough behavior, magnesium divalent cations had a similar effect as those with any salt addition [34]. Along with sodium and potassium, a chloride salt mix improves dough behavior to a higher level than in the case when only sodium chloride was added in the dough recipe, such as the data previously published by Voinea et al. [21]. This will affect bread quality, which will generally present lower values for the bread's physical characteristics than those obtained when sea salt was added in the bread recipe. The bread color characteristics indicate a darker color for samples with the increased level of SS addition in the bread recipe. This effect is due to the Maillard reaction, which takes place between amino acids and reducing sugars. The presence of SS will lead to a less intense fermentation of yeast in the initial stages of bread making, a fact that will allow a higher number of sugars and amino acids in the dough in the baking phase. SS will slow down the yeast activity, a fact that will increase the number of free sugars from the dough system, which will be involved in the Maillard reaction in the last stage of bread making [3,43]. From a textural point of view, the SS addition decreases the cohesiveness and resilience values and at high levels increases the firmness and gumminess ones. The increase in firmness and gumminess at high levels of SS addition in the wheat flour may be explained by gluten protein behavior, which becomes more compact by SS addition in the wheat flour. More of these variations of textural values may be correlated with a specific volume of bread sample values [44], which increased at high levels of SS addition and decreased at low ones. In general, the bread sensory characteristics were improved by SS addition in the wheat flour. This sensory improvement may have multiple explanations. First of all, SS addition has an important contribution to the Maillard reaction. Besides the fact that during this reaction the bread darkens in color, flavor compounds are also formed which contribute to the sensory perception of the bread [43,45]. Moreover, it is well known that SS decreases the amount of free water in the bread, a fact that will decrease the flavor compound's volatility [3]. Moreover, SS addition improves the bread's physical characteristics, which presented higher values than the control sample, a fact that will influence sensory perception of the bread by consumers. The most important effect that SS has on the bread's sensory characteristics is its salty taste, an effect which the Na^+ ions from its content have on consumers [46]. Therefore, the increased amount of SS addition in the bread recipe may improve the taste perception of the bread by consumers. SS is a salt with low sodium content. However, increasing its amount in the bread recipe will increase the sodium content from the bread samples. According to our data, bakery products with levels up to a 0.6% SS addition in the wheat flour can be classified according to the European Commission (EC) Regulation no. 1924/2006 as products with a very low sodium content because their value is less than 0.04 g/100 g of sodium. Bread products with the addition levels of 0.9, 1.2 and 1.5% SS incorporated into the bread recipe may be classified as products with low sodium content because they have values lower than 0.12 g/100 g of sodium [3,7]. Generally, the sodium chloride from bread varied between 1.00–1.50 g/100 g [22]. Our formulation leads to backery products with 10–15 times lower sodium than those obtained in regular bread products, which may have a major impact on daily sodium intake.

5. Conclusions

Bread and other bakery products are some of the major sources of sodium in the daily diet of the population. Therefore, most initiatives to reduce sodium consumption focus on reducing the sodium chloride content in these products. In many European countries, bread, together with a wide range of bakery products, accounts for about 30% of the daily dietary sodium intake. The reduction of sodium from bread by using sea salt with low sodium content may be an alternative for bakery producers. The effect of SS from a rheological point of view was similar to those obtained by using sodium chloride salt in bread making. Its addition resulted in a strengthening effect on wheat flour dough by increasing its stability, dough development time, energy, dough resistance and decreasing the degree of softening after 10 min. During heating, SS addition increased peak viscosity, gelatinization temperature, temperature at maximum peak viscosity and falling number values. In terms of fermentation behavior, the SS addition improved the rheofermentometer values, which presented maximum values to a 0.6% SS addition in the wheat flour. The bread quality was better appreciated from the sensory point of view with the increased level of SS addition in the wheat flour. The bread with SS incorporated into the bread recipe presented higher physical values and lower textural characteristics compared to the control sample. Depending on the dose of SS added in the wheat flour, the bread samples may be marketed as bread samples with a very low sodium content or with low sodium content if SS exceeds a 0.9% addition in the bread recipe.

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