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THE EFFECT OF SALT REDUCTION ON DOUGH MIXING PROPERTIES AND ARABIC BREAD SENSORY CHARACTERISTICS

by
CAMILLE ANTOINE GEORGES

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CAMILLE ANTOINE GEORGES

Approved by:

Dr. Ammar Olabi, Associate Professor Department of Nutrition and Food Sciences	Advisor
Dr. Imad Toufeili, Professor Department of Nutrition and Food Sciences	Member of Committee
Dr. Hani Tamim, Associate Professor Department of Internal Medicine	Member of Committee

Date of thesis defense: April 7, 2016

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AN ABSTRACT OF THE THESIS OF

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The relationship between salt/sodium intake and chronic diseases is well established. Bread is the main staple in the Middle East and was shown to be a significant contributor to salt intake. Salt fulfills important functional and sensory properties in bread and decreasing its level could significantly impact the overall dough and bread qualities. The objectives of this work were to assess the effect of salt reduction on the mixing properties of Arabic bread dough as well as the sensory characteristics of the resulting bread.

Three treatments, NaCl, agglomerated salt (Ag-NaCl), and partial substitution of NaCl with 30% KCl (NaCl-KCl), were used at 5 different salt levels (0.3, 0.6, 0.9, 1.2 and 1.5% wt/wt in flour) to develop 15 versions of Arabic bread. Farinograph measurements were conducted to analyze the mixing properties of dough. Breads were evaluated for acceptability with 72 panelists, and the optimal salty taste level in the samples was determined using a Just-About-Right (JAR) scale. A two-stage discrimination test was carried out to assess differences between the treatments and a selected control (0.9% NaCl). Descriptive analysis (DA) was used with 12 judges to characterize the key attributes of the different bread samples. Because taste is crucial when reducing salt, the salty equivalence of the salt substitutes was also determined using the magnitude estimation method. All sensory analyses were conducted using the Compusense at-hand® sensory evaluation software.

Farinograph results showed that decreasing salt levels significantly impacted mixing properties of dough. Decreasing salt levels lowered the stability and the time to breakdown while the mixing tolerance index of the dough increased ($p<0.05$). Acceptability of bread was not significantly dependent on salt content; however, ratings on the JAR scale showed that the optimal salt level in bread was 0.9% NaCl. At levels of 0.6% and 0.9% NaCl-KCl and 0.6% Ag-NaCl, bread samples were not different from the 0.9% NaCl treatment ($p<0.05$). DA showed that omitting salt in Arabic bread significantly increased sweetness, yeasty odor and flavor and decreased the perception of saltiness ($p<0.001$). No major differences in texture were observed. Magnitude estimation pointed out that 0.67% Ag-NaCl and 1.13% NaCl-KCl were needed to achieve an equivalent saltiness to 0.9% NaCl in Arabic bread, suggesting a respective 25.6% and 12.1% sodium reduction without compromising on taste.

Keywords: Salt, Sodium, Bread, Acceptability, Sensory evaluation.

CONTENTS

ILLUSTRATIONS

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ABBREVIATIONS

2-AFC	2-Alternative Forced Choice
3-AFC	3-Alternative Forced Choice
AI	Adequate Intake
Ag-NaCl	Agglomerated sodium chloride
α	Alpha significance level
AACC	American Association of Cereal Chemists
AUB	American University of Beirut
ANOVA	Analysis of Variance
ACE	Angiotensin Converting Enzyme
ADH	Antidiuretic Hormone
BP	Blood Pressure
BU	Brabender Unit
×	By
Ca	Calcium
$CaCl_2$	Calcium chloride
CCHS	Canadian Community Health Survey
CO_2	Carbon dioxide
CVD	Cardiovascular Disease
cm	Centimeter
CASH	Consensus Action on Salt and Health
R^2	Correlation Coefficient
°C	Degree Celsius
DBP	Diastolic Blood Pressure
DRI	Dietary Reference Intake
DLS	Digitalis-like Substance
S-S	Disulphide
$	Dollar
EAR	Estimated Average Requirement
et al.	Et alii (and others)

ECF	Extra-Cellular Fluid
FSA	Food Standard Agency
GLM	Generalized Linear Model
g	Gram
>	Greater than
hr	Hour
HCl	Hydrochloric acid
HTN	Hypertension
i.e.	Id est
INTERMAP	International Population Study on Macronutrients and Blood Pressure
INTERSALT	International Study of Salt and Blood Pressure
JAR	Just-About-Right
kg	Kilogram
LASH	Lebanese Action on Sodium and Health
L.L.	Lebanese Lira
≤	Less than or equal to
L	Liter
Log	Logarithm
$MgCl_2$	Magnesium chloride
µg	Microgram
µL	Microliter
µmol	Micromole
MENA	Middle East and North Africa
mg	Milligram
mL	Milliliter
mmHg	Millimeter of Mercury
mmol	Millimole
mN.m	Millinewton Meter
min	Minute
MTI	Mixing Tolerance Index

MSG	Monosodium Glutamate
NHANES	National Health and Nutrition Examination Survey
ppm	Parts per million
/	Per
%	Percent
K	Potassium
KCl	Potassium chloride
PC	Principal Component
RDA	Recommended Daily Allowance
RAA	Renin Angiotensin Aldosterone
Na	Sodium
NaCl	Sodium chloride
Na/K ATPase	Sodium-Potassium Adenosine Triphosphatase
SPSS	Statistical Package for the Social Sciences
SBP	Systolic Blood Pressure
TTB	Time to Breakdown
UL	Tolerable Upper Intake Level
UK	United Kingdom
USA	United States of America
WA	Water Absorption
wt/wt	Weight by Weight
WASH	World Action on Salt and Health
WHO	World Health Organization

CHAPTER I

INTRODUCTION

The Neolithic period marks an important transition in food production and consumption with the first appearance of agriculture that allowed food to be supplied to a larger proportion of the population. Prior to that era, human nutrition depended exclusively on what was obtained from hunting and gathering. When grains and cereals began to be harvested for food, they became an important staple in the human diet (Mondal & Datta, 2008). Different techniques were discovered to enhance the digestibility of grains, and the development of technology saw the advancement in the preparation and processing of cereals to end up with a very familiar product that is bread.

The four main ingredients in bread preparation are flour, water, yeast and salt. Salt, also known as sodium chloride (NaCl) fulfills various important rheological, technological, and sensory properties in bread manufacturing. It imparts flavor, controls yeast growth and fermentation rate, improves the texture of the product, and reduces its physical and microbiological spoilage (Beck, Jekle, & Becker, 2012c).

However, recent data on sodium intake suggests that populations around the world are consuming much more sodium than is physiologically necessary. This elevated intake has been associated with a number of illnesses including hypertension, cardiovascular diseases and stroke (F. J. He & MacGregor, 2010). Numerous international health agencies in cooperation with the food industry have recommended a salt intake level of 5 – 6 g daily, representing roughly half of the current consumption (Who & Consultation, 2003).

Bread and dough-based foods, considered as staple in Lebanon and the Middle-East, are a major source of sodium in the diet (Almedawar et al., 2015). Therefore, any reduction in the level of salt in bread could positively impact the local/regional health and would be a major step towards decreasing the prevalence of hypertension.

The aims of this present study are to investigate the influence of three different types of salt, used in five levels (0.3, 0.6, 0.9, 1.2 and 1.5% wt/wt of flour basis), on the empirical rheological properties of wheat dough and the sensory properties of bread, and to determine the equivalent amount of salt replacers (potassium chloride, agglomerated sodium chloride) to induce the same degree of “ideal” saltiness provided by sodium chloride in Arabic bread.

CHAPTER II

LITERATURE REVIEW

A. Sodium and Human Health

1. Sodium and Human Physiology

Sodium (Na) is a vital mineral to human health and is involved in a wide range of physiological mechanisms, including the control of fluid and electrolyte balance, as well as the preservation of the electrochemical gradient by the active transport of molecules through the Na/K ATPase pump that ensures low levels of intracellular Na and high levels of potassium (K). Na is the primary extracellular cation that is found at a concentration of 140 – 145 mmol/L and is present in relatively low concentrations (10 mmol/L) in the intracellular medium (Penney, 2008). Na balance is tightly controlled by the interaction between neuro-hormonal and intra-renal mechanisms that participate in the maintenance of the extracellular fluid (ECF) volume and arterial blood pressure (BP). The kidneys play a major role in the homeostasis of the "milieu intérieur" as described by Claude Bernard and Na balance is mediated by the ability of the kidneys to retain and excrete large or small quantities of Na, depending on the situation (Penney, 2008). The nephron is the functional unit of the kidney. Na is filtered at the glomerulus level and is reabsorbed at different locations in the tubules under the influence of aldosterone, according to the body's needs (Michell, 2014). Excretion of Na is mediated by mechanisms called pressure natriuresis and pressure diuresis that are triggered by altered ECF volumes and variations in BP. BP is one of the strongest physiological systems to maintain Na balance and ensure tissue perfusion (Karppanen & Mervaala, 2006). Alterations in the reabsorption of Na are mainly due to smooth muscle cells that have the ability to constrict or dilate blood vessels to mediate glomerular Na filtration. Most of the filtered Na (66%) is reabsorbed in the proximal tubule; around 25% is reabsorbed in the loop of Henle, very minimal amounts (5%) in the distal tubule and 0 – 5% of Na's reabsorption takes place in the collecting duct, depending on dietary intake and the amounts to be eliminated. The renal regulation of Na is interrelated with the maintenance of the ECF. It is regulated by the equilibrium between the amount of Na intake and that of its excretion by the kidneys that should be almost equal (Palmer, Alpern, & Seldin, 2008). Therefore, blood/plasma volumes and thus blood pressure are governed by the amount of Na in the body (Katarzyna Stolarz-Skrzypek & Staessen, 2015) and adjustments are made by different feedback mechanisms that tightly regulate Na intake as well as its excretion, to allow humans to live normally at different levels of Na exposure (Palmer et al., 2008). However, conservation of blood pressure is not only dependent on intra-renal mechanisms exclusively. In fact, Na balance also involves neuro-humoral mechanisms that include the natriuretic hormone, the renin-angiotensin-aldosterone (RAA) system and the nervous system (Karppanen & Mervaala, 2006).

Dietary Na is almost entirely (95%) absorbed throughout the gastro-intestinal tract, with the highest absorption occurring in the small intestines regardless of the amount ingested (Michell, 2014). However, recent data has shown that populations around the world consume much more Na than is physiologically necessary. Indeed, the average salt intake, as shown by the International study of Salt and blood pressure (INTERSALT), ranges between 7.5 and 11.5 g per day in industrialized countries (Ha, 2014). Therefore, excess Na is not retained in the body and is instead eliminated through urine and sweat (Michell, 2014). In this case, an elevated plasma Na concentration activates water intake by drinking (thirst mechanism) that results in a temporary increase in ECF volume. The suppression of the secretion of aldosterone stimulates Na excretion and restores normal serum concentrations (Karppanen & Mervaala, 2006). On the other hand, a reduction in Na intake increases water and sodium retention through the stimulation of the sympathetic nervous system. In this situation, the release of renin activates the RAA system that stimulates the production of angiotensin I, which is then converted to angiotensin II by the Angiotensin Converting Enzyme (ACE), and the release of the anti-diuretic hormone (ADH) from the hypophysis, to cause the renal arteriole to constrict and slow down the blood flow in the glomerulus to, ultimately, increase Na and water reabsorption (Beevers, Lip, & O'Brien, 2001).

2. The Adverse Health Effects of Excess Dietary Salt Intake

The evidence between excessive sodium consumption, increased blood pressure and consequently cardiovascular diseases is derived from numerous population studies and is widely accepted (Adrogué & Madias, 2007). As a matter of fact, a high sodium diet is positively associated with hypertension and cardiovascular risks (stroke and cardiovascular diseases), according to a meta-analysis of 15 observational studies (Strazzullo, D’Elia, Kandala, & Cappuccio, 2009).

a. <u>Sodium and Hypertension</u>

By definition, hypertension (HTN) results when systolic blood pressure (SBP) (blood pressure of arteries when the heart contracts) exceeds 140 mmHg with a diastolic DBP (BP when the heart relaxes) over 90 mmHg. There are different types of HTN and could be classified as either primary (or essential), or secondary. The essential type is the most common form of HTN and accounts for 90-95% of cases (Beevers et al., 2001). The cause for the development of primary HTN is still unclear as several factors contribute to its onset including environmental factors such as aging, excessive dietary salt intake, obesity, sedentary lifestyle as well as genetic factors that remain poorly understood until today (F. He & MacGregor, 2009; Lifton, 1995). The secondary type of HTN accounts for the remaining 5-10% of cases and appears as a result of another underlying illness, usually a renal disease (Beevers et al., 2001).

HTN has become an alarming public health issue given that its prevalence is constantly increasing, as much in western countries as in other regions in the world (Baudin et al., 2009). This condition is often referred to as “silent killer”, due to the fact that high blood pressure is generally not accompanied with any visible symptom. Because of its late onset, HTN is considered to be a major risk for the development of strokes, heart failure, myocardial infarction and renal diseases. An analysis of worldwide data on HTN has shown that the prevalence varies with age, gender and race (Kearney et al., 2005). Roughly 26.4% of the adult population worldwide had HTN back in 2000 and it is estimated that the condition will affect 29.4% of the adult population in 2025. In the Middle East and North Africa (MENA) region, Sibai et al. (2010) showed that the highest prevalence rates of reported HTN were in Bahrain (42.10%) and Syria (40.60%), followed by Morocco (33.60%), Qatar (32.10%) and Lebanon (31.20%) (Mehio Sibai et al., 2010). Furthermore, a more recent cross-sectional survey conducted in all six Lebanese provinces showed that the average hypertension prevalence increased to 36.9%. This prevalence was reported to be higher in males, in those with advancing age and higher income levels (Matar et al., 2015).

According to He and MacGregor (2009), there is a relationship between high salt intake and HTN (F. He & MacGregor, 2009). Haddy (2006) proposed two indirect effects of how sodium raises BP: the increase of digitalis-like substances (DLS) in the blood and the decrease of K levels in the blood due to renal elimination (Haddy, 2006). DLS are substances secreted by the hypothalamus and adrenal glands that inhibit the cardiovascular membrane and reduce the activity of the Na, K-ATPase pump, thereby increasing the contraction of the heart and arteries, leading to an increase in BP. Additionally, excess salt intake forces K to be excreted, and the resulting decrease in potassium plasma concentration causes vessels to constrict and increase BP. However, responses to salt intake do not affect BP the same way for everyone. Indeed, an interesting concept proposed that individuals can be classified as being either "Salt-Sensitive" or "Salt-Resistant" (Weinberger, 1996). Briefly, salt-sensitive individuals retain sodium regardless of the amount of salt ingested, while salt-resistant individuals excrete very high amounts even when consumption is high (Ben-Dov & Bursztyn, 2011; Farquhar, Edwards, Jurkovitz, & Weintraub, 2015). This may be due to many physiological considerations such as altered renal functions, abnormalities in the RAA system or even alterations in adrenergic receptor activity (Weinberger, 1996). Sensitivity to dietary salt intake is very complex and is determined by genetic mechanisms, age, weight, ethnicity, low-birth weight, kidney disease and associated illnesses. Nevertheless, this concept still remains a theory and findings from population studies should be taken into account concerning salt and HTN.

Most studies confirm the lowering effect of low salt intake on BP in both normotensive and hypertensive subjects. For example, a meta-analysis found that a modest restriction of 1.7g/day has the ability to lower systolic BP by 2.0 mmHg and diastolic BP by 1.0 mmHg in normotensives, while in hypertensive individuals, systolic BP was lowered by 5.0 mmHg and diastolic BP by 2.8 mmHg (F. He & MacGregor, 2002).

b. Sodium and Cardiovascular Diseases

Considerable amount of evidence has associated excessive dietary salt intake with Cardiovascular Diseases (CVD) through HTN. In a meta-analysis of 19 independent cohorts with 177,025 participants from 6 different countries (U.S.A, Finland, Japan, Netherlands, Scotland, and Taiwan) and a follow-up of 3.5 to 19 years, a high salt intake was positively associated with CVD outcomes in 13 different cohorts (Strazzullo et al., 2009). Other studies have shown consistent results with Strazzulo et al. Indeed, in a prospective Japanese study of 2 cohorts of 91,225 subjects, high salt intake was shown to increase risks of CVD (Takachi et al., 2010). Additionally, a prospective study of 12,267 adults, the Third National Health and Nutrition Examination Survey, examined the relationship between sodium and potassium intake with the risk of CVD. Results have shown that a higher sodium to potassium ratio is linked to an increased risk of mortality linked to CVD after a median follow-up time of 14.8 years (Yang et al., 2011). Moreover, the NHANES I Epidemiologic Follow-Up Study, a prospective study of 13,643 men and women with no history of heart failure, followed up for 19 years, showed that the incidence of developing congestive heart failure increases with an elevated dietary sodium intake of > 2600 mg/day (J. He et al., 2001). Independently of BP, salt intake is a risk factor of Left

Ventricular Hypertrophy. It was postulated that salt may cause hypertrophy of the heart by increasing intravascular volume and enhancing protein synthesis of heart cells (Frisoli, Schmieder, Grodzicki, & Messerli, 2012).

c. <u>Sodium and Other Diseases</u>

Other adverse health effects unrelated to cardiovascular outcomes have also been reported. Sodium intake was linked to deaths by strokes and intra-cerebral hemorrhages in a study conducted in Japan (Frisoli et al., 2012). The mechanism proposed is still unclear but salt is thought to cause vascular oxidative stress resulting in "artery thickness, stiffness, and platelet reactivity", ultimately causing strokes (De Wardener & MacGregor, 2002). Moreover, other studies have suggested the association between elevated sodium intake, osteoporosis and kidney stones. In fact, when sodium excretion by the kidneys increases, urinary calcium (Ca) excretion is directly promoted by a Na-Ca interaction in the kidneys during reabsorption, and indirectly by modulating levels of parathyroid hormone. Since Ca is a major component in most renal stones, salt seems to be a major factor in developing them (F. J. He, Jenner, & MacGregor, 2010). It was also found in animal studies, that higher dietary salt has deleterious effects on bone thus promoting bone resorption that may lead to osteoporosis if the calcium density in the diet is low (Massey & Whiting, 1996). Data obtained from the INTERSALT study from 24 countries has shown the strong likelihood of developing stomach cancer with higher salt intake (Joossens et al., 1996). Furthermore, an increase in salt intake among hypertensive patients alters normal renal functions with increased filtration rate, vascular resistance and more seriously protein excretion (De Wardener & MacGregor, 2002).

B. Sources of Sodium in Food

Since excessive Na intake may lead to adverse health effects, it is important to understand the contributors of Na in the diet. The most common source of Na in human nutrition is sodium chloride (NaCl), also informally referred to as "table salt". Some food sources naturally contain sodium such as celery, beets, milk, eggs and meat, albeit present in very little amount. Mattes and Donelly (1991) showed that 75% of total Na intake is provided by processed foods as manufacturers add salt in very large quantities to enhance flavor as well as to extend the shelf-life of different foods by inhibiting the growth of food-borne pathogens. Furthermore, it has been estimated that only 10% of total salt intake comes from natural food sources and that discretionary salt, added during cooking or at the table, accounts for another 5 – 10% of the total intake in western societies (Anderson et al., 2010). Various systematic surveys, notably in Canada, United Kingdom and Australia, have analyzed the sodium content of different processed foods mostly purchased by the population (Mhurchu et al., 2011; Tanase, Griffin, Koski, Cooper, & Cockell, 2011; Webster, Dunford, & Neal, 2010). It was found that the highest sodium-containing foods were processed meat, canned foods, snack foods like potato chips, pickled vegetables, marinades, spreads, baking powder, and sauces including Asian and tomato sauces. Nevertheless, it is important to note that a better indicator of Na consumption would be the frequency of consumption of foods that contain sodium. The Canadian Community Health Survey (CCHS) v2.2, conducted in 2009, evaluated the contribution of sodium intake from different food groups. Among all foods included in the survey, bread was one of the major contributors of sodium in the Canadian diet (14% equivalent to 430 mg Na/day). Despite the fact that bread may not contain high amounts of sodium, its major contribution is due to the fact that it is a staple food in many societies and is very frequently consumed (Fischer, Vigneault, Huang, Arvaniti, & Roach, 2009). Other foods that contributed to high dietary sodium intake were: 9% (276 mg/day) from processed meat, 6% from pasta (176 mg/day), 5% from cheese (167 mg/day), and around 5% from canned and pickled vegetables (159 mg/day). Moreover, the National Health and Nutrition Examination Survey (NHANES) in the United States analyzed the different foods that contributed the most sodium in the American population in 2005-2006 and findings were somehow similar to the Canadians. Breads contributed to 7.3% sodium, 6.8% were provided from chicken dishes and pizzas, 6.3% from pasta dishes, 5.1% from cold cuts and deli meats, and 4.4% from condiments (National Cancer Institute, 2006). Furthermore, according to the INTERMAP study (Anderson et al., 2010), data from the 2002 Chinese Health and Nutrition Survey showed that 82.8% of sodium in the diet is provided by table salt added during cooking, 6.4% from soy sauce, 3.8% from bread and noodles, and 0.6% from monosodium glutamate (MSG), a popular flavor enhancer widely used in Asian cuisine. Moreover, a recent study on 903 families living in Beijing showed that 60.5% of dietary salt is consumed at home, where approximately 90% came from cooking (Zhao et al., 2015).

Therefore, these data revealed a very large contribution of manufactured and ready-to-eat foods to overall dietary sodium intake in industrialized countries, which validates the idea that sodium in food processing is “hidden” and people are not aware of the large amount of sodium that they ingest. Indeed, sodium is found under various forms including MSG, sodium hydroxide, sodium phosphate and sodium bicarbonate (Luft, Zemel, Sowers, Fineberg, & Weinberger, 1990). However, very limited data exists in the Middle East and North Africa (MENA) region on current dietary salt intake. These countries represent a region where the prevalence of nutrition-related diseases is expanding alarmingly, primarily due to fast nutrition transitions and high rates of development and urbanization (Mehio Sibai et al., 2010). A study conducted in Iran in 2013 assessed the sodium intake of children aged between 3 and 10 years old, and data showed that bread, cheese and ready-to-eat snacks were the major sources of sodium in their diets (Kelishadi, Gheisari, Zare, Farajian, & Shariatinejad, 2013). It was also reported that processed foods contribute about 67% of the average daily salt intake in the Lebanese population. Bread and dough-based foods were found to be important contributors of sodium in the Lebanese diet, providing around 25% of total daily salt intake, followed by processed meats (12%) and cheese (10%) (Almedawar et al., 2015).

C. DRIs for Sodium and Overview of its Dietary Intake around the World

The Dietary Reference Intakes, also known as DRIs, are nutrition recommendations established by the Institute of Medicine that provides reference values for different nutrients according to gender and different age groups (Institute of Medicine, 2006). These values were developed to decrease the risk of any nutrient-related deficiency and/or excess in the population (Institute of Medicine, 2000). DRIs for sodium include two different values: the Adequate Intake (AI) and the Tolerable Upper Intake Level (UL). Since there is insufficient evidence and dose-response data available for sodium, the Estimated Average Requirement (EAR) and the Recommended Daily Allowance (RDA) could not be established. AIs for sodium were developed based on available experimental and observational studies and they were fixed at levels thought to meet the needs of the majority of the population (Murphy, Guenther, & Kretsch, 2006), to replace minimal sodium losses (i.e. via sweat), and to guarantee adequate nutrient consumption other than sodium (Institute of Medicine, 2005). AIs for sodium were set at 1,500 mg/day for those between 9 and 50 years of age, with lower values for the sensitive population.

The UL is a reference that indicates the maximal amount of a certain nutrient to be consumed daily without the risk of developing hazardous health effects such as toxicity or the onset of a nutrient excess related disease. The UL for sodium was fixed to limit its dietary intake as well as to decrease the possibility of developing hypertension and associated illnesses including cardiovascular diseases, osteoporosis, gastric cancer and renal diseases. The DRIs for sodium are summarized in Table 1. The World Health Organization (WHO), in 2003, fixed a recommended intake target of ≤ 5 g of salt per day per person which is equivalent to ≤ 2000 mg sodium per day (Who & Consultation, 2003).

Table 1. Dietary Reference Intakes for sodium by age category

Age Group (years)	Adequate Intake Level (mg/day)	Tolerable Upper Level (mg/day)
1 – 3	1,000	1,500
4 – 8	1,200	1,900
9 – 13	1,500	2,200
14 – 50	1,500	2,300
51 – 70	1,300	2,300
>70	1,200	2,300

In many parts of the world, sodium intake from different food sources remains considerably high compared to the recommended intake levels listed above (Brown, Tzoulaki, Candeias, & Elliott, 2009). One of the first international epidemiological studies, INTERSALT, estimated sodium intake using a standardized protocol for the measurement of 24-hour urinary sodium. This observational cross-sectional study grouped 10,079 subjects across 52 INTERSALT centers around the world, aged between 20 and 59 years, with urinary sodium ranging from 0.2 to 242.1 mmol/24 hr equivalent to 0.012 to 14.2 g Na (Ha, 2014; F. J. He & MacGregor, 2010; K Stolarz-Skrzypek et al., 2012). Results have shown that only 4 centers had a low salt intake defined as ≤ 3 g/day, and most of them ranged between 6 and 12 g/day (F. J. He & MacGregor, 2010). Highest values for sodium excretion were found in Asian countries such as China, ranging from 5.35 g/day (233 mmol/day) in women and 5.95 g/day (259 mmol/day) in men whereas lowest values were reported among a Brazilian Indian tribe: 18 mg/day (0.8 mmol/d) in men and 23 mg/day (1.0 mmol/day) in women (Elliott & Brown, 2007). The Chinese nutrition survey conducted in 2002 showed that there was no significant increase in the consumption of sodium in the population, but the traditional Chinese diet is already high in sodium.

The INTERMAP study of nutrient intake among different samples in China (n = 3), Japan (n = 4), United Kingdom (n = 2) and USA (n = 8) evaluated dietary patterns with cardiovascular diseases between Eastern and Western countries among males and females (Zhou et al., 2003). In accordance to the INTERSALT study, the highest mean values of sodium excretion were reported in Northern China reaching values as high as 6.88 g/day (299 mmol/day) in men and 5.82 g/day (253 mmol/day) in women. In the Japanese samples, 24-hr sodium excretion values ranged from 4.49 – 5.06 g/day (195 – 220 mmol/day) in men and 3.68 – 4.60 g/day (160 – 200 mmol/day) in women. Concerning the United Kingdom samples, excretion values were the lowest and were 3.70 g/day (161 mmol/day) in men and 2.92 g/day (127 mmol/day) in women. Moreover, according to the CCHS v2.2, Canadians older than 1 year old consume on average around 3100 mg/day based on 24-hour recalls, but sodium added at the table from sodium chloride was disregarded (Garriguet, 2007). Average sodium intake in the Canadian population is well above the established DRIs for all age and gender categories. Indeed, for Canadians > 19 years, the daily sodium intake revolves around 3600 mg/day among males and 2700 mg/day in females. Results have also shown that sodium intake was higher among teenagers and adults, and declined with age. This is due to the fact that sodium intake is directly related to the energy intake (Taylor & Henry, 2010). In the MENA region, the study in Iran showed that on average, children consume high amounts of sodium and intake was estimated to be around 201.8 ± 11.8 mg/day (Kelishadi et al., 2013). Furthermore, a national survey conducted by Nasreddine et al. showed that 55% of the adult population in Lebanon consumed more sodium than the recommended levels set by the Institute of Medicine (L Nasreddine et al., 2013). In all studies, sodium intake is higher among males indicating the higher energy intake in that category compared to females.

D. Sodium Reduction Initiatives

1. Sodium Reduction Strategies

As covered previously, excess dietary sodium is associated with numerous adverse health effects. Therefore, it is important to reduce this intake at the population level, even by modest levels, to effectively decrease cardiovascular mortality, as well as health care expenses. Reducing daily salt intake by 3g (i.e. 1200 mg Na), like the level achieved in Finland, could potentially decrease new cases of myocardial infarction, stroke and death in general by a respective average of 72,000, 49,000 and 68,000 annually. Moreover, this initiative could save up to $24 billion in health care costs each year (Appel & Anderson, 2010; Webster, Dunford, Hawkes, & Neal, 2011).This intervention is considered essential and has proven to be very effective in hypertensive patients, especially in those with resistant HTN, as both systolic and diastolic BP were significantly decreased (Pimenta et al., 2009). Consequently, several strategies have been proposed by numerous international health organizations (WHO, Pan-American Health Organization), governmental, non-governmental organizations, and even the food industry to implement this reduction. These include: 1) reformulation of foods by the industry in terms of sodium content; 2) nutritional and educational campaigns to increase awareness and behavior about sodium among the population; 3) the development of innovative technologies to compensate for low salt levels; 4) the constant monitoring of sodium intake in the population (Dötsch et al., 2009).

About 32 salt reduction campaigns were identified all over the world, mostly concentrated in Europe, to set a recommended intake to approximately 5g per person per day (Webster et al., 2011). The majority of the countries involved (n=26) have "voluntary reformulation programs", while Portugal and Argentina have "mandatory reformulation programs" for salt reduction in food products to motivate the food industry to meet the proposed targets. In the US, decreasing dietary salt was always advisable but no concrete action has been taken yet (F. J. He et al., 2010).

The United Kingdom (UK) has been very successful at implementing these programs and their strategy serves as a model for other countries to follow. Setting the Consensus Action on Salt and Health (CASH) group in 1996, the UK was able to progressively reduce salt in manufactured foods. The Food Standard Agency (FSA) launched the strategy in 2003, started consumer education and awareness campaigns in 2005 and set sodium targets for each food category for the industry to meet in a given period of time (F. J. He et al., 2010). Initially, the aim was to establish a “stepwise reduction” in salt added to food by decreasing around 10 to 20% of salt at first and repeating that step after 1 to 2 years in order to ensure a 40% reduction in processed goods as suggested by the Salt Model based on national sodium intake data (K. Charlton, Webster, & Kowal, 2014). Similarly, Canada established the Sodium Working Group in 2007 and their strategy is very similar to that of the UK’s. Canada aims to tackle this issue by ensuring a multi-level approach to lower sodium intake of its population to 2300 mg/day by 2016. However, as far as manufactured foods are concerned, reducing their sodium content will require efforts in reformulation and more importantly, gradual decreases with time (Hutchinson, L’Abbe, Campbell, & Tanka, 2010). These gradual reduction strategies are usually not detectable by the taste receptors (Dötsch et al., 2009) , do not cause any food safety and processing-related issues, and are therefore less likely to be subjected to consumer rejection (K. Charlton et al., 2014; F. J. He et al., 2010).

Clear labels are crucial for consumers and the “traffic light” system is now widely adopted in the UK for warning purposes. This color coding system of “green, amber and red” for low, medium and high salt content dramatically affected behavioral purchases and highly influenced consumer decisions (F. J. He et al., 2010). Finland also adopted this strategy by implementing compulsory warning labels to warn their consumers of high sodium content. In Ireland, because limits for sodium have been established, manufacturers can claim their product as “low salt”, “very low salt” or “salt free” (Webster et al., 2011).

Evaluating the outcome within a year, people in the UK were more aware of the salt target and the proportion shifted from 3% to 34%. According to the industry, changes in consumer behaviors were observed as the interest in low-salt foods kept rising. A total reduction of 15% was achieved in processed foods, with an interesting 33% reduction in branded breads and a 40% reduction in breakfast cereals. Following the IOM's report on reducing salt intake strategies, 16 manufacturers have claimed to have cut down on sodium levels in certain products in the US (F. J. He et al., 2010). Moreover, table salt sales were reduced by half suggesting a reduction of a gram of salt per day (K. Charlton et al., 2014; F. J. He et al., 2010). In Lebanon, a national survey conducted by Nasreddine et al. has shown that people are still very unaware of the health consequences of a high salt diet and its contributors in the diet. Most of the people are not concerned by the amount of sodium they ingest and do not look at the food labels, as they do not seem to be very comprehensible (Lara Nasreddine, Akl, Al-Shaar, Almedawar, & Isma'eel, 2014).

Globally, after the CASH success in the UK, the World Action on Salt and Health (WASH) group was founded in 2005 to establish groups specific to each country with suitable strategies to decrease sodium intake worldwide by pressuring multi-national companies to decrease the salt content of their products (F. J. He et al., 2010). The Lebanese Action on Sodium and Health (LASH) group was established in Lebanon, in order to take action on this matter at the national level based on the WHO recommendations (Almedawar et al., 2015). Efforts are now oriented, as a first step, to reduce the sodium levels in Arabic bread and dough-based foods because of their relatively high contribution to sodium intake in the Lebanese diet.

2. Sodium Reduction in Bread

According to Lynch, Dal Bello, Sheehan, Cashman, and Arendt (2009), reducing the salt content in bread is feasible from a technological point of view. Bread is a basic and an important item of many societies' diets, and because of its high consumption frequency, it is a target for sodium reduction (Quilez & Salas-Salvado, 2012).

Almost all European countries are following the sodium reduction strategy in bread. The French and Spanish strategies have adapted focusing on bread reformulation, reducing salt content from 2.0% (based on wt/wt flour basis) to 1.8% and 2.2% to 1.8% respectively. Reducing salt in bread involves the same approach as previously seen: gradual salt reduction and taste compensation for low-salt levels by substituting Na with other mineral salts (Dötsch et al., 2009).

a. <u>Gradual Salt Reduction in Bread</u>

Sodium reduction is very delicate and challenging, as a major cut back will negatively impact the final product and will lead consumers to switch to other products with higher salt contents (Dötsch et al., 2009). Indeed, while decreasing sodium levels, several factors should be taken into account including sensory, textural and preservation properties (Belz, Ryan, & Arendt, 2012). Taste is an essential determinant of food choice and consumption, and the disadvantage with reducing the salt concentration in bread is the unpalatability that results from the drop in flavor. Both salty and sweet perceptions are inhibited, while the perception of bitterness is enhanced (Breslin & Beauchamp, 1997).

Lucas, Riddell, Liem, Whitelock, and Keast (2011) demonstrated that reducing sodium more than 50% in hash browns leads to lower acceptability.

The approach of gradually reducing salt in bread consists of slowly adapting the consumer's preference for less salty taste (Dötsch et al., 2009). For example, Girgis et al. (2003) showed that gradually reducing sodium in white bread by a quarter (25%) is achievable over a period of 6 weeks and does not affect consumer acceptability. These results seem promising and this strategy could be used by the food industry to meet the requirements for sodium and, at the same time, prevent them from losing valuable customers (Liem, Miremadi, & Keast, 2011). A study on the effect of reduced sodium bread on consumption in a 12-week period supported these findings, whereby regular bread (i.e. containing standard levels of sodium) was administered during the first and last three weeks of the experiment and bread with 31% reduced sodium was provided in the middle period of 6 weeks. This reduction did not affect bread consumption and no difference was noticed by the participants (Brinsden, He, Jenner, & MacGregor, 2013). When consumer acceptability and the purchase intent of 20% and 30% sodium-reduced bread were assessed, the above sodium reductions did not have any effect on sensory properties of bread including overall acceptability, color, flavor and texture (La Croix et al., 2015). This method of taste adaptation enables people to alter their perception and liking towards very salty foods and to perceive them as "less preferred and less pleasant" (Beck et al., 2012c). Bertino, Beauchamp, and Engelman (1982) successfully demonstrated, in a 5-month study, that reducing overall dietary sodium intake is directly related to the preference of lower salt levels in products due to taste adaptation and that once adapted, maintaining a low sodium diet with a preference for low sodium foods should be very easy. Additionally, lower levels of sodium chloride can be easily detected compared to those with higher sodium intakes (Beck et al., 2012c).

Nevertheless, it should be kept in mind that there is a point where further reductions will become noticeable, and that this strategy, although efficient, takes time to materialize. Consequently, other alternatives have been proposed whereby salty perception is expected to remain the same while lowering sodium levels.

b. Taste Compensation of Low Sodium Levels in Bread

In order to improve the acceptability of sodium-reduced food products, many ingredients were used to exert the same functionality as NaCl in terms of perceived saltiness. The most commonly applied method is the partial substitution of NaCl with other mineral salts that do not contain sodium. The difficulty here resides in the appropriate selection of non-sodium salts as they affect wheat dough properties such as elasticity and bread characteristics such as flavor and texture quite differently (H. He, Roach, & Hoseney, 1992). Potassium chloride (KCl) is one of the most popular salt replacers used in bread and has been tested in many studies. It has been well established that a diet rich in potassium and low in sodium provides health benefits and could potentially decrease blood pressure. Many studies have suggested replacing 20 – 40% of NaCl with KCl in bread, given that such levels do not negatively affect the properties of wheat dough or the baking quality of the resulting bread (Salovaara, 1982a). However, the main disadvantage is, once again, the unpalatability due to high KCl concentrations. A replacement of more than 40% of NaCl with KCl results in poor bread flavor with an undesirable bitter after-taste (Braschi, Gill, & Naismith, 2009). Therefore, to overcome this situation, a low substitution level of sodium chloride with KCl seems to be the most suited alternative to preserve the acceptability of bread. In this case, the bitterness and metallic off-tastes are well attenuated by the low KCl concentration, and at the same time, by the presence of enough sodium ions to provide the required saltiness. Results from different sensory analyses showed that it is possible to replace sodium chloride with KCl up to 32% in wheat bread without compromising on flavor (Braschi et al., 2009; K. E. Charlton, MacGregor, Vorster, Levitt, & Steyn, 2007). Other mineral salts that could partially compensate for low sodium levels include calcium, magnesium and lithium chloride. Although lithium chloride provides a very salty taste, its use in bread is not recommended for its low stability to heat and its toxic effect (Beck et al., 2012c). Calcium chloride ($CaCl_2$) has shown to provide sweet, sour and bitter tastes at low concentrations and exerts a combination of salty and bitter taste at higher levels (Tordoff, 1996). Concerning magnesium chloride ($MgCl_2$), it was shown that a 10% NaCl substitution is possible without negatively impacting bread flavor (Salovaara, 1982b). Because none of these salts provide a clean salty taste such as the one obtained with NaCl, efforts were oriented to decrease the bitterness perceived by using substances like sweeteners (sucrose, trehalose, thaumatin), 2,4-dihydrobenzoic acid, or even adenosine 5'-monophosphate (AMP) as a "bitter blocker" (Beck et al., 2012c).

Additionally, new technologies are currently being developed and employed with the availability of other salts, such as agglomerated NaCl, that have the ability to increase the salty taste perception but further investigations are needed concerning a product like bread. Ag-NaCl microspheres are NaCl crystals that are spray-dried and transformed into hollow crystalline microspheres of smaller particle size and density. It is claimed to be a salt-reducing ingredient due to the clean salty taste it provides by increasing surface area to volume of the salt particles. Ag-NaCl could, in principle, reduce Na levels up to 25% - 50% in many products without compromising on flavor (Mueller, Koehler, & Scherf, 2016).

E. Arabic Bread: An Essential Item in the Middle Eastern Diet

1. Bread Consumption in Lebanon and the Middle East

Bread has been a staple food in several civilizations' diets for about 10, 000 years because of its important nutritional value, its relatively low price, its socio-cultural significance, and the simplicity of cooking the cereals that contribute to the making of bread. It is also an important component of the Middle Eastern diet and takes a different form from conventional breads (Quail, 1996). It is often referred to as Arabic bread, "two-layered flat" (2LF) bread or even "Pita" bread and exists in many different types (Williams, El-Haramein, Nelson, & Srivastava, 1988). In Lebanon, bread is one of the most consumed items by the population, and is included at practically every meal. In 2006, a study conducted in Lebanon aimed to evaluate the food consumption pattern in a sample of Lebanese adults. Results showed that the average consumption of cereals and cereal-based products like bread was around 146.2 g/person/day, and this intake represented around 35% of the total average caloric intake (Lara Nasreddine, Hwalla, Sibai, Hamzé, & Parent-Massin, 2006).

However, this proportion was much lower than that of 1961, where cereals and breads contributed to approximately 49.3% of the total energy intake in the Lebanese diet.

This declining trend was attributed to the fact that cereals and breads were gradually replaced by high fat foods in the diet, marking a shift from the traditional diet towards a more westernized diet (Lara Nasreddine et al., 2006). In Egypt, the food consumption patterns are quite different from Lebanon. Cereals and cereal-based products' intakes were around 459 g/person/day (Saleh, Brunn, Paetzold, & Hussein, 1998). Additionally, in Syria, annual consumption of bread for 1986 was estimated to be 172 kg/person/year representing around 353 g/person/day (El-Haramein & Adleh, 1994). The relatively high intake and the dependence on bread as a main source of energy can be explained by low income and the affordability of such products (Musaiger, 1993). Since Arabic bread is an essential item to the Lebanese diet, understanding its processing and the different specific characteristics seems important, especially when it is considered as a potential contributor to salt intake in the local diet.

2. Commercial Processing of Arabic Bread

The steps involved in Arabic bread processing do not differ from those of other types of leavened breads, from mixing to baking except for the formation of dough sheets, the shorter final fermentation time, and the exposure to higher temperatures during baking that is partly responsible for the two layers (Williams et al., 1988).

a. <u>Ingredients</u>

Arabic bread is essentially constituted of four different ingredients that are flour, water, yeast, sugar and salt. Unified wheat flour (type 75 – 80% extraction) is one of the main ingredients used in the production of Arabic bread and its quality is directly related to the type of flour used (Qarooni, 1996). Flour is a complex mixture of starch and proteins that interact together to provide the bulk and structure of bread. Water is the second most abundant ingredient and is responsible for the formation of dough and the soft texture of the resulting product. Dry active yeast contributes to the fermentation and rising of the dough during proofing stages. Finally, sodium chloride is a very important ingredient that cannot be compromised as it plays many roles in dough and bread.

Arabic bread formulation described by Qarooni (1996) and Toufeili (1999) is summarized in Table 2 below.

Table 2. Proportion of ingredients used in Arabic bread formulation based on flour weight.

Ingredients	%
Unified Flour	100.0
Water	56.0
Sugar	3.0
Yeast	1.0
Salt	1.5

b. <u>Dough Formation</u>

In order to form the dough, dry ingredients are first blended together as per the formulation in Table 2. Water is then added to hydrate all components and mixed until a homogeneous dough is obtained. However, it is important to note that the mixing time is a crucial variable in the final quality of the resulting breads (Qarooni, 1996). Proper mixing ensures the development of a strong gluten network providing the structure of the dough as well as its elasticity and extensibility (Toufeili et al., 1999). The consistency of the dough does not only depend on the amount of water added but also on the quality of the used flour and the temperature of the dough that should be around 30°C (Quail, 1996). Overmixing the dough leads to the breakdown of the developed gluten structure and the damage of the starch granules to result in a very sticky dough that is difficult to handle. Furthermore, experiments have shown that overmixing the dough results in “blistering and lack of symmetry” of breads (Qarooni, 1996).

After mixing, the dough is allowed to rest for about 15 to 30 min and this step is known as “bulk fermentation”. Qarooni (1996) has shown that increasing “bulk fermentation” time from 30 to 90 min impacts Arabic bread characteristics such as darker crumb color, lower blistering and “evenness” of layer thickness.

The dough is then divided into smaller individual pieces that will serve as loaves, and rounded into balls to ensure symmetry and consistency after introduction in dough sheeter (Quail, 1996). “Intermediate proofing” allows the rounded dough balls to rest for about 15 min in a controlled environment (temperature and humidity), and is an essential step in Arabic bread processing. This resting time will enable the “relaxation “ of the gluten network to prevent the dough from sticking when handled at later stages (Qarooni, 1996; Quail, 1996).

Sheeting of the dough is the next important step in making Arabic bread. When introduced in a sheeter, dough pieces are passed in a two-stage “pressing roller” where they are first degased, flattened and turned oval in shape and then rounded to a thickness of 2 mm for best quality when introduced at a temperature of 500°C (Qarooni, 1996).

After having sheeted the dough pieces, the round sheets are given around 15 min to rest during the “final proofing” stage in a temperature-humidity controlled cabinet. This proofing time is necessary to allow the dough sheets to rise and form two even layers when baked (Qarooni, 1996; Quail, 1996).

c. Baking

The specificity of Arabic bread is attributed to the double layers that form during baking. This is due to the extremely high temperatures the dough sheets are exposed to. Usually, baking of Arabic bread is carried out at 400°C for 90 seconds (Quail, 1996) . However, baking temperature is directly related to the thickness of the dough sheets that are being introduced (Qarooni, 1996). Very thin-layered bread is usually baked at 650°C for 18 to 20 seconds. When different baking conditions and dough thickness were evaluated, it was concluded that baking very thin dough sheets at very high temperatures for a short period of time gives the best results in terms of quality. Although it is very demanded in various Middle-Eastern countries, it is rather difficult to constantly maintain such elevated temperatures (Qarooni, 1996). The bread is then cooled until the interior temperature reaches 35 – 37°C and is transferred for packaging.

3. Specific Characteristics for Arabic Bread Quality

Acceptability of double-layered flat breads like Arabic bread is related to many factors and differs from one person to another and from a geographical location to another. The main factors that determine Arabic bread acceptability are related to its handling quality and internal characteristics. These include bread pliability and pocketing (or seperation of the two different layers). The external appearance such as size, shape, color of crumb, thickness of layers and presence of blisters also contribute to the overall acceptability (Qarooni, 1996). An "ideal" loaf of Arabic bread should be round in shape, with a crust of consistent golden brown color and smooth surfaces lacking cracks and blisters, and a crumb of white color. The loaf should be soft and rollable, and should separate easily.

Crumb texture, also known as mouthfeel, is an important characteristic in assessing the quality of Arabic bread, and should be soft and moist. Finally, staling strongly contributes to the reduced acceptability of Arabic bread, and should therefore be evaluated. Bread staling is a complex phenomenon that occurs when moisture is partly lost but is also due to an alteration of the starch-protein interaction and starch retrogradation. This results in a dry, crumbly and bland loaf of bread. Moisture loss can be prevented by adequate packaging in regular polyethylene bags and freezing of loaves (Quail, 1996).

F. Dough and Bread Characteristics

1. The Role of Yeast in Bread Processing

Baker's yeast, commonly known as *Saccharomyces cerevisiae*, is a unicellular yeast and grows by budding where a daughter cell, smaller than the mother cell, buds off. Yeast is added to dough and has a major role during the fermentation step and is at the heart of bread processing (Chiotellis & Campbell, 2003). Growth of yeast requires warmth, available moisture and nutrients such as starch and sugars (Ali, Shehzad, Khan, Shabbir, & Amjid, 2012). Yeast is thermo-sensitive and exposing it to high temperature will cause its cells to die. On the other hand, low temperatures i.e. refrigeration or freezing slow down its activity. The optimal temperature for yeast growth ranges between 24 and 25°C. During proofing, these conditions are ensured: yeast metabolizes fermentable sugars like glucose

($C_6H_{12}O_6$) in dough to produce carbon dioxide (CO_2) and ethanol (C_2H_5OH), as per the following reaction:

$$C_6H_{12}O_6 + \text{yeast} \rightarrow 2C_2H_5OH + 2CO_2$$

Nevertheless, the rate of fermentation depends on the availability of fermentable sugars (Ali et al., 2012). The bubbles of CO_2 produced by yeast have the ability to raise the dough by expanding the gluten proteins. Therefore, it is essential to evenly distribute the bubbles in the dough mixture by kneading it adequately so that it could expand further during the remaining fermentation steps (Madigan, Martinko, & Parker, 2003).

Yeast activity in bread processing is highly dependant on environmental factors such as "air-drying, freeze-thawing, and high sucrose concentrations" (Akbar, Aamir, Moazzam, Muhammad, & Muhammad, 2012). Although available sugar is a source of nutrient for yeast growth, its excess increases the osmotic pressure on the membranes of yeast and activity becomes thus limited (Tanaka - Tsuno et al., 2007).

Additionally, some studies have investigated the effect of yeast on dough rheology. Different mechanisms have been postulated but further investigations remain necessary. Doughs fermented with 0.76% yeast (wt/wt based on flour basis) and those with 2.00 µmol hydrogen peroxide (H_2O_2)/g flour had the same effects on dough rheology indicating that yeast could be considered as an oxidizing agent during fermentation (Liao, Miller, & Hoseney, 1998). Moreover, these findings also supported the evidence that yeast generates H_2O_2 during fermentation of wheat dough, thus altering its rheology.

From a nutritional point of view, studies have shown that *Saccharomyces cerevisiae* strains contain high levels of vitamin B9, also known as folic acid, with values ranging from 24.5 – 35.2 μg/g dry yeast (Akbar et al., 2012). This means that vitamin B9 content in finished fermented products like bread should be expected to be high. As a matter of fact, breads leavened with yeast contained 2.5 times more folic acid than those leavened with regular baking powder (Kariluoto et al., 2004).

2. The Role of Wheat Gluten in Bread Processing

Wheat seeds are anatomically composed of three structural parts: the bran, the germ and the endosperm that constitute around 13%, 2% and 80 – 85% of dry weight respectively (Goesaert et al., 2005). These three parts contain different proportions of protein that can be classified into different fractions according to Osborne: albumins, globulins, glutelins and prolamins. Albumins and globulins do not affect dough properties, and are found in the germ and the outer part of the endosperm. Glutelins (or glutenin) and prolamins (or gliadin) are found in the endosperm of the grain and are essential in the development of wheat dough (Cauvain & Young, 2007). They are identified according to their different molecular weights as well as their solubility and account for 40-50% and 30-35% of total protein respectively.

When a mixture of wheat flour and water is worked, the storage proteins form a gel and a strong network. This is attributed to the gluten proteins that confer to wheat flour doughs the elastic properties that are required in bread making. The behavior of gluten proteins is due to their unique amino acid composition (Wieser, 2007). Gluten is majorly composed of glutamine (30-35%) and proline (14%), and this composition is found in both gliadin and glutenin fractions. However, they both exert different functionalities, each of them providing a certain property of the gluten network formed during mixing.

Gliadin is the gluten fraction that has a low molecular weight and that is soluble in ethanol according to Osborne. Upon hydration, this fraction provides viscosity and extensibility that will permit the dough to rise during fermentation by allowing air bubbles to expand (Cornell, 2012). Therefore, gliadin strongly contributes to the specific rheological properties of gluten.

On the other hand, glutenin is a polymer constituted of different polypeptides (subunits) that have high and low molecular weights when dissociated, and are usually soluble in dilute acid. Upon hydration, glutenin behaves like an elastic solid and provides elasticity and strength to the dough. It is therefore responsible for the dough's cohesiveness and resistance to extensibility.

In bread processing, gluten has the ability to bind water as much as double its weight. The gluten structure is attributed to the covalent disulphide (S-S) bonds between cysteine molecules in both gliadin and glutenin (Shewry, Tatham, Forde, Kreis, & Miflin, 1986). Gliadins are reffered to as monomers and have the ability to form S-S bonds within molecules. However, glutenins can form inter-molecular S-S bonds between the different subunits constituting the polymer. Because of the high glutamine content, the amide side chain can easily create hydrogen bonds between proteins by accepting electrons (Cauvain & Young, 2007). Moreover, more than 35% of gluten amino acids contain hydrophobic side-chains and are important in the development and stabilization of the gluten network. During mixing of the dough, glutenin polymers can form "sheets" by the destruction and reconstruction of S-S and hydrogen bonds (Cauvain & Young, 2007). Gluten also has the ability to entrap gas bubbles within the dough. During the baking process, gluten is denatured with heat and releases water to gelatinize the surrounding starch molecules and to obtain the shape, volume, resistance and elasticity of the final product.

3. The Role of Wheat Starch in Bread Processing

Starch is the main carbohydrate in wheat grains and serves as a stored energy source for the crop. It is thus the major component of wheat flour and its proportion depends on the extraction rate. For example, it constitutes about 70% of wheat flour of 80% extraction based on 14% moisture (D'appolonia & Rayas-Duarte, 1994) and exists in the form of rounded granules. It is usually composed of 75% amylopectin (branched chain) and 25% amylose (linear chain). Starch is widely used in the food industry for its tfunctionality and specifically its ability to interact with water when heated, in other terms, starch gelatinization. In bread processing, starch plays many important roles: it is a source of readily available sugar as a source of nutrient for yeast during fermentation, it interacts with gluten proteins to give a strong dough structure, and it absorbs water from the surrounding to gelatinize during baking (Chiotelli, Pilosio, & Le Meste, 2002)

Gelatinization of wheat starch starts when the temperature reaches around 60-65°C and when water from the denaturated gluten proteins is released, causing an increase in viscosity when the granules swell upon heating. Furthermore, during baking, a part of the amylose fraction diffuses out of the starch granule and dissolves into the surrouding aqueous solution, that sets into a gel upon cooling. However, a study reported that several factors affect starch gelatinization in dough systems: low-water content, sugar and salt seem to slow down the process by increasing the temperature range by 20-30°C (Ghiasi, Hoseney, & Varriano-Marston, 1983). Moreover, gluten proteins during baking retain part of the absorbed water and do not entirely release it for swelling of starch granules (Ghiasi et al., 1983). Therefore, the water availability is limited and bread should be considered as a system with “restricted” water content.

Following baking and during storage, the physical properties of bread begin to alter and the process involves starch. These properties are due to the migration of water from crumb to crust and starch retrogradation, a chemical rearrangement of structure, leading to an increased firmness in bread or staling (Beck, Jekle, & Becker, 2012b). The reasons for bread staling remain unclear, but several mechanisms have been proposed. Retrogradation of the amylopectin part was thought to cause staling given that no changes in the amylose gel were observed. However, other options are to be taken into consideration such as a starch-gluten interaction, or water redistribution (Gray & Bemiller, 2003).

G. The Effect of Salt on Dough and Bread Characteristics

1. The Effect of NaCl on Yeast and Wheat Dough Fermentation

Investigations on the effect of NaCl addition and dough leavening rate have shown interesting results. In a Japanese study, different doughs, of wheat bread, were prepared with varying salt levels and allowed to proof under controlled humidity and temperature conditions. The expansion rates were measured for each dough and results revealed that the optimal salt concentration for a maximum extension of 96% in 20 min was 2% based on a wt/wt flour basis. Interestingly, increasing salt levels up to 8% in dough slowed down the process (Toshiyuki & Yasuhide, 2013). According to this study, at low levels, salt promotes the linkage between gliadin and glutenin fractions thus expanding the network. These findings were confirmed when low levels of NaCl (0.5 – 1% based on flour mass) were shown to stimulate yeast activity by increasing dough volume and where elevated NaCl levels (3.5 – 4% based on flour mass) inhibited the leavening ability of yeasts (Beck et al., 2012b).

As described previously, high sugar concentrations exert high osmotic pressure on the yeast membranes and slow down their activity. Salt has also the ability to apply osmotic stress effect on the membranes and presses the water out of the cells thus causing partial dehydration and disrupting yeast activity, resulting in low dough volumes (Ali et al., 2012; Beck et al., 2012b). It can be concluded from the above studies that salt is important to regulate yeast activity in bread making and to avoid a very gassy and sour dough due to over-fermentation.

2. The Effect of NaCl on Wheat Gluten and Dough Rheology

Several studies have demonstrated that sodium chloride affects the behavior of gluten proteins in wheat dough by strengthening the gluten network during mixing of ingredients (Beck, Jekle, & Becker, 2012a; Danno & Hoseney, 1982). Based on empirical and subjective evaluations, doughs without added NaCl were perceived as being stickier and more difficult to handle (Danno & Hoseney, 1982). The possible mechanism behind these observations is attributed to the charged amino acid side chains in the different gluten fractions. In wheat dough, the amino acids that constitute the gluten proteins are positively charged and repulse each other. This leads to the establishment of a very weak connection within the gluten proteins (Beck et al., 2012a). However, the addition of NaCl provides negatively charged ions to the dough system and neutralizes the repulsion between the charged amino acids on the surface of gluten proteins thus favoring network formation.

By definition, rheology is the study of flow and deformation behavior of liquids and solids due to applied stress. In dough measurements, rheology is a quantitative measure that provides information on the quality of the gluten network and is widely used to explain the physical properties of dough. The cereal industry widely uses empirical rheological devices such as the amylograph, extensograph, farinograph and the mixograph to generate data and provide valuable information for performance assessment (Amjid et al., 2013).

A study showed that salt enhances dough strength up to a certain level after which adverse effects can be observed (Danno & Hoseney, 1982). Using a mixograph, six salt levels, based on flour weight, were assessed: 0%, 0.5%, 1%, 2%, 5% and 10%. Dough strength was enhanced with salt levels ranging from 0.5 to 5% whereas dough collapsed with a 10% salt level. Lynch et al. (2009) attempted to establish the association between NaCl and dough extensibility and extension with the means of an extensograph and a texture analyzer. Dough samples were prepared with no yeast, different salt levels i.e. 0%, 0.3%, 0.6% and 1.2% based on wt/wt flour basis, and the same amount of water for all treatments. No differences were observed in extension of doughs containing 0.3% to 1.2% NaCl, but there was a significant difference between doughs with 0% and 1.2% NaCl. Overall, it was observed that even small amounts of salt can improve physical dough properties.

Studies have suggested that salt reduces dough water absorption when evaluated with a farinograph at constant consistency of 500 Brabender Units (B.U.) (Farahnaky & Hill, 2007) . Water absorption (WA) is an important parameter that indicates the amount of water required for the hydration of flour components and the development of the gluten network (Bassett et al., 2014). Another study confirms these findings where reducing salt levels from 4% to 0% based on a wt/wt flour basis increased WA from 57.5% to 58.7% (Beck et al., 2012a). Replacing NaCl with mineral salts such as KCl or $CaCl_2$ decreased the WA rate (Kaur, Bala, Singh, & Rehal, 2011). This tendency of increasing WA with lower salt levels can be described by the fact that a competition exists between Na^+ and Cl^- ions and water molecules on the surface of the gluten protein.

Furthermore, Farahnaky and Hill (2007) reported that mixing time for proper dough development increases with salt. Indeed, at a constant consistency of 500 B.U., a gradual increase of 1% salt on a wt/wt flour basis increases dough development time by 30 seconds. However, substituting NaCl with calcium or potassium salts did not affect development time (Bassett et al., 2014; Kaur et al., 2011). As stated previously, addition of NaCl helps in developing a more interconnected protein structure that increases dough stability. Dough stability is the time during which the dough maintains a maximal consistency of 500 BU. Reducing NaCl levels decreased stability from 18.47 min to 3.73 min when doughs containing 4% and 0% salt respectively were evaluated with a farinograph (Beck et al., 2012a). Replacing NaCl with Ca or K salts in different proportions also affected stability. Indeed, a replacement of 25% and 50% with KCl improved dough stability whereas a complete replacement showed a decrease in stability (Kaur et al., 2011).

Another study showed that increasing the proportion of Ca salts in white flour by 50, 70 and 80% decreased the stability time of the obtained dough (Bassett et al., 2014).

The degree of softening has been found to increase with decreasing salt levels from 2.2 millinewton.meter (mN.m) at 4% NaCl to 6.87 mN.m at 0% NaCl (Beck et al., 2012a). As the replacement of NaCl with mineral salts increased, the degree of softening values increased (Kaur et al., 2011). The lower stability that results from lowering NaCl or significant substitutions is associated with higher softening values (Bassett et al., 2014). Overmixing the dough leads to very sticky dough that has also lost its elasticity. Danno and Hoseney (1982) reported that these effects can be can be reversed by the addition of NaCl.

However, dough and gluten properties are not only limited to the effect of salt given that other factors such as temperature, gluten quality, pH, mixing time and speed seem to influence dough rheology as well (Farahnaky & Hill, 2007).

3. The Effect of NaCl on Wheat Starch

Different studies have suggested the effect of salt on starch gelatinization properties. Sodium chloride, added at a level of 2 % wt/wt flour basis, has been shown to increase the gelatinization temperature range from 56°C to 62°C (Ghiasi et al., 1983). Furthermore, similar findings were reported in a multi-measurement study when wheat starch was dissolved in water containing levels of NaCl ranging from 0 – 16% and analyzed with a Differential Scanning Calorimeter (DSC) (Chiotelli et al., 2002). Nevertheless, both studies indicate that increasing the salt content causes a decrease in gelatinization temperatures. The effect of NaCl on wheat starch properties can cause alterations in bread volumes, where higher gelatinization temperatures due to increasing salt levels leaves more time for the dough to expand while baking resulting in loaves with higher volumes (Beck et al., 2012b).

Lynch et al. (2009) showed that salt is also involved in starch retrogradation. Bread loaves with different salt levels were baked and stored for 120 hours. During evaluation, breads with 0% NaCl were significantly firmer than those prepared with 1.2% NaCl. It was hypothesized that salt retains moisture in the crumb and prevents water from migrating, thus slowing down the retrogradation process.

4. The Effect of NaCl on Final Bread Properties

It has been well established that the addition of salt influences several parameters related to the final quality of bread including volume, shelf-life and sensory properties.

a. Bread Volume

A commonly measured parameter when assessing the final quality of bread is the specific volume, which is defined as the "ratio of bread volume to bread weight" (Belz et al., 2012). In theory, low salt levels in dough enhance its expansion due to excessive gas production, resulting in greater volumes. However, Lynch et al. (2009) failed to demonstrate this theory, concluding that breads prepared with 0.3% and 0.6% NaCl compared to 1.2% NaCl did not show any significant difference in specific volume and moisture contents. Nonetheless, alhough these results were not significant, a trend was observed suggesting that low salt bread loaves were associated with increased volumes.

b. Microbial Shelf-Life

Sodium chloride is widely used as a preservation agent and this property is crucial for the development of safe and stable food products. Therefore, salt reduction and/or the partial substitution of NaCl not only affects shelf-life, but the functionality of certain products as well. Mold spoilage is an important issue in the baking industry given that molds are the main spoilage agents in bread (Belz et al., 2012; Samapundo, Deschuyffeleer, Van Laere, De Leyn, & Devlieghere, 2010). In bread, salt reduces water activity by applying an osmotic pressure on microbes' cells preventing them from growing. A study aimed to evaluate the effect of salt reduction and replacement on the growth of spoilage molds like *Aspergillus niger* and *Penicillium roqueforti*, isolated from rye and corn breads respectively, concluded that the use of non-sodium salt replacers decreases the microbial stability with respect to both strains (Samapundo et al., 2010).

c. Sensory Properties

The addition of sodium chloride to wheat dough enhances the sensory properties of the final product by impacting the texture, flavor and color. Although odor has not been shown to be influenced by salt, some effects were noticed due to the interaction between salt and yeast (Belz et al., 2012).

i. Texture

Texture is one of the most crucial sensory factors related to consumer acceptability of bread. Salt plays a role in the development of the gluten network during mixing and results in an even crumb structure. Lynch et al (2009) showed that bread without salt had less large air cells in the crumb when compared to breads with added salt.

A trained sensory panel compared the texture of wheat bread with different salt levels 18 hours after baking. Breads were assessed by hand and mouth and were described as “soft” and having high “crust resistance”. However, after storage, only breads containing 1.2% NaCl remained acceptable whereas the reduced salt breads had an “unacceptable” texture.

ii. Color

It has previously been stated that salt has the ability to slow down fermentation leaving some “free” sugars for the Maillard reaction that occurs during baking. It is a complex reaction that forms during heating of products involving proteins and reducing sugars therefore providing the desired flavor and color of products like bread. During baking, melanoidins are formed through the Maillard reaction, and other reactions take place such as caramelization to contribute to the golden-brown color of the crust. Low-salt breads have lighter crusts for the simple reason that, in the absence of sodium, yeast metabolizes more sugar during fermentation, leaving less available sugar for the coloration of the crust.

iii. Flavor

Sodium chloride is well known to impart flavor by providing a salty taste and by masking off-flavors such as bitterness. Compromising on salt greatly affects the flavor of bread and intereferes with consumer acceptability. Bread was described as “yeasty” and "acidic", by a trained descriptive panel, when no salt is added (Lynch et al., 2009). During baking, the Maillard reaction produces subtances called melanoidins that are partly responsible for the flavor of bread. It has been shown that the light crust of salt-reduced breads, caused by the lack of these subtances, provides an "insipid" taste with a more pronounced yeasty flavor as described by the sensory panel (Bassett et al., 2014; Belz et al., 2012).

H. The Concept of Taste Equivalence

New product development allows the food industry to continuously improve food quality and the well-being of consumers. Evidence from different studies has shown that reducing salt in manufactured foods has become a necessity. The formulation and development of low-salt foods are achievable through the use of different salt substitues such other chloride salts like KCl and $MgCl_2$, phosphates or flavor enhancers (de Souza et al., 2013). Similar studies have suggested the substitution of sucrose in many products like fruit beverages and dairy desserts with different artificial sweeteners due to numerous health concerns (Freitas, Dutra, & Bolini, 2014; Morais, Morais, Cruz, & Bolini, 2014). In order to successfully substitute NaCl or sucrose in recipes, a full understanding of ingredient functionality is required. Indeed, adequate knowledge in the sensory characteristics of the potential substitutes is essential as much as obtaining knowledge about their suitable concentrations and their equivalency when compared to sodium chloride and sucrose.

Taste equivalence allows the comparison of different substances with a reference ingredient, and is commonly tested by magnitude estimation through the power function of

Steven's law, proposing a relationship between the magnitude of a stimulus and its perceived intensity. A recent study on butter aimed to develop different formulations with various NaCl substitutes (KCl, MSG, Potassium phosphate), to assess their salting potency, and to create a sensory profile of the different treatments (de Souza et al., 2013). Results showed that the partial replacement of NaCl with other salts was not very convenient. It has been reported that these substances provide intense undesirable off-flavors that have the ability to cover their salty perceptions. Panelists who participated in the sensory tests gave lower ratings in terms of saltiness with increasing concentrations of salt substitutes. Furthermore, it was shown that MSG and potassium phosphate required levels as high as 3 times the standard concentration of 1% NaCl to obtain an equivalence in the salting power. On the other hand, KCl and NaCl had similar salting power when the amount of KCl used was lower (1.2%) to result in equivalent saltiness and sensory perceptions of butter prepared with 1% NaCl. Very similar results were observed in cream cheese confirming the potency of the different substitutes used (Silva, Souza, Pinheiro, Nunes, & Freire, 2014). However, other strategies need to be implemented in order to attenuate the after-tastes that occur from these substances such as the partial replacement with NaCl or the combination of different salts to enhance the salty perception.

Taste equivalence is therefore an important method when aiming to reduce a crucial ingredient like NaCl or sucrose in food products by assessing the taste potencies of different potential substitutes through the power function that is defined as: $S = a.C^n$

where S is the sensation perceived, C the concentration of the stimulus, a the antilog of the y intercept of the linear function and n the slope of the linear function. From the power function, the equivalent concentration of sodium chloride substitute can be estimated and plotted in a graph for visual representation as shown in Figure 1.

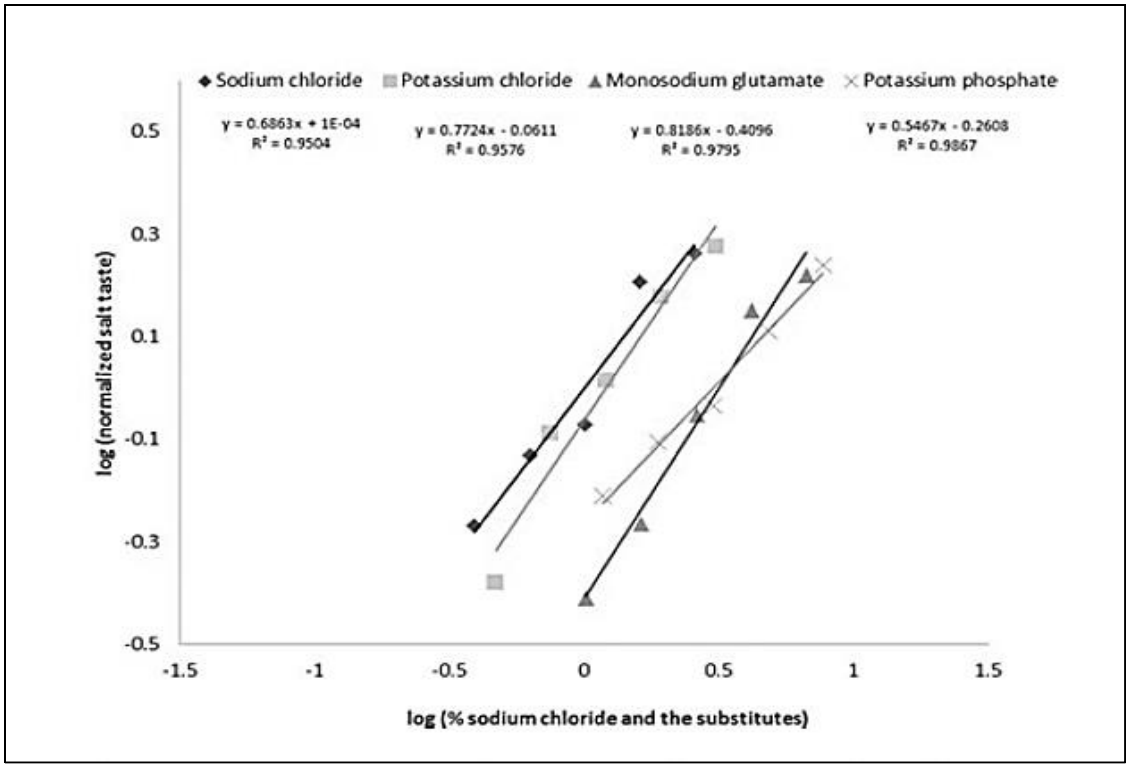


Figure 1. Linearized power function for butter prepared with NaCl and different salt substitutes (de Souza et al., 2013).

CHAPTER III

MATERIALS AND METHODS

A. Arabic Bread Processing

1. Formulations

Arabic bread samples were prepared at the pilot plant of the Faculty of Agricultural and Food Sciences at the American University of Beirut (AUB) according to the procedure described by Toufeili et al. (1999).

Table 3. Formulation of experimental bread loaves.

Ingredient	% (based on flour weight)	Amount (g)
Wheat flour	100	1000
Water	56	560
Sugar	3	30
Yeast	1	10
Salt	1.5	15

The experimental samples were prepared with three types of food-grade salts: commercial sodium chloride (NaCl), potassium chloride (KCl, Cargill, U.S.A) and agglomerated NaCl (Ag-NaCl, Soda-Lo®, Tate & Lyle, U.K.). Salts were added at different levels: 0%, 0.3%, 0.6%, 0.9%, 1.2% and 1.5% based on a wt/wt flour basis to give 16 different treatments. A 30% NaCl substitution was used for the KCl treatment based on previous research that had shown the adequacy of this substitution level (Charlton, MacGregor, Vorster, Levitt, & Steyn, 2007). The experimental design is illustrated in Figure 2.

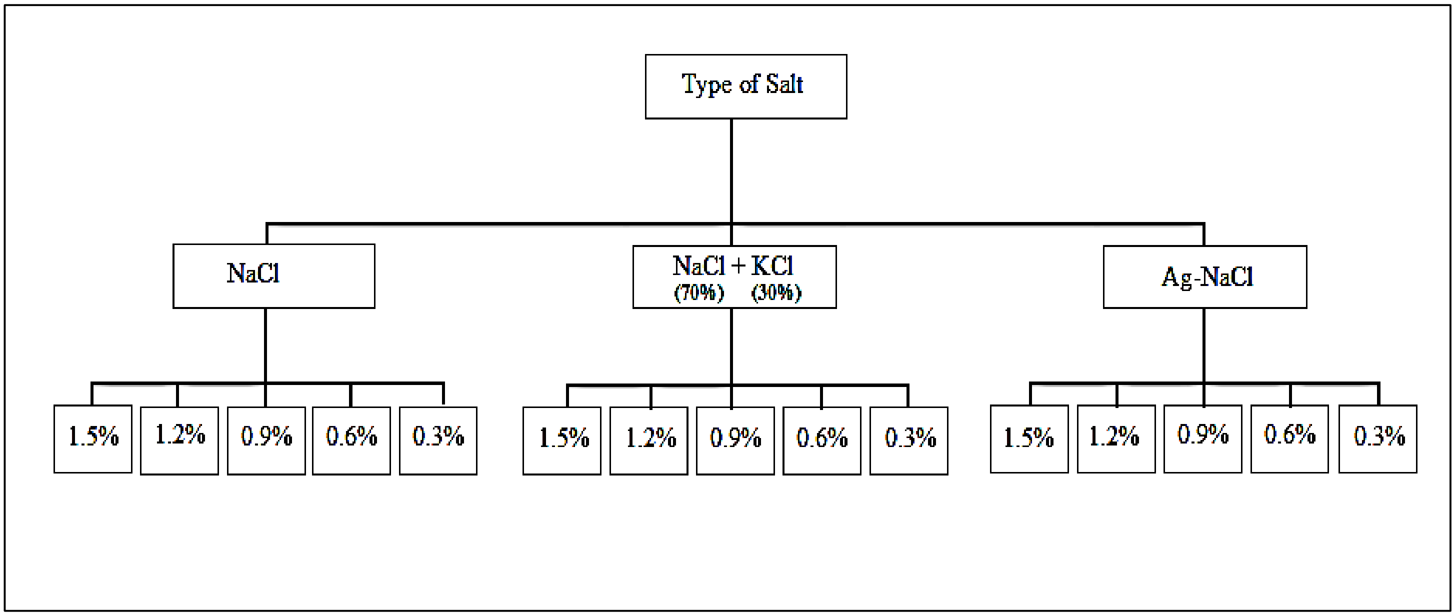


Figure 2. Experimental Design for types of salts used and percentage of salt on a wt/wt flour basis.

2. Processing and storage

The ingredients were first measured on a digital balance (SB 16001; Mettler Toledo, Switzerland). They were then mixed for 15 min at the lowest speed (speed 1) in a dough mixer (0016, Solarco Equipment, Beirut, Lebanon) until a smooth and continuous dough was obtained. Water was added 10 seconds after having mixed the dry ingredients to avoid the formation of lumped particles. The resulting dough was put in a bowl, sprinkled with flour and covered with a damp cloth to prevent its surface from drying. It was then placed for a first fermentation in an incubator at 40°C (GCA Corporation, Bedford, Pennsylvania) for 15 min. The dough was then divided and rounded into small balls of approximately 40 g each, placed on a wooden board sprinkled with flour, covered with a damp cloth and fermented for another 30 min in the incubator at 40°C. After the second fermentation, the dough was sheeted into uniform circular flat sheets using a dough sheeter

(0017, Solarco Equipment, Beirut, Lebanon). They were then placed again on a wooden board and proofed in the incubator at 40°C for 15 min before baking. The proofed sheets were then introduced in a conveyor Pita bread oven (TOS, Bramco SARL, Choueifat, Lebanon) at a temperature of 500°C until an optimal golden brown color was obtained (about 50 – 55 sec). Arabic bread loaves were finally cooled to room temperature, placed in polyethylene bags and stored in a walk-in freezer at – 18 °C until all sensory and chemical analyses were conducted.

B. Chemical Analysis

1. Sodium and potassium determination

Bread samples were analyzed for sodium and potassium content by Atomic Absorption Spectrophotometry as described in the AACC Method 40-71.

Triplicate samples weighing around 3g of each bread sample were weighed and placed in a previously ignited porcelain ashing crucible. Samples were dry-ashed at 500°C for 12 hours in a muffle-furnace (Lindberg/Blue M, Netherlands). Ashed samples were dissolved in 10 ml HCl (1+1) (Appendix IX) and quantitatively transferred into acid-washed 100 ml volumetric flasks mounted with a filter paper (Whatman 3 qualitative, CAT No. 1003-110) and a funnel and then adjusted to volume with deionized water. 100 µL of bread solution, 8 ml deionized water and 2 ml 0.5% cesium chloride stock solution were transferred into a 15 ml tube. Sodium and potassium standards were prepared by dilution with deionized water of a standard solution of 1000 ppm. Sodium and potassium contents were then calculated using the following formula:

Na, K (mg/100g) = $\frac{(C_s - C_b) \times V \times D}{S \times 10}$

where

C_s = Concentration of sample (μg/ml), C_b = Concentration of blank (μg/ml)

V = original volume (ml)

D = Dilution factor (dilution volume (ml) / aliquot for dilution (ml))

S = Sample weight (g)

C. Empirical Rheology of Dough

The farinograph is one of the most widely used instruments to evaluate and understand the rheological behavior of dough. The Brabender Farinograph-E was used to record the mixing properties of doughs resulting from the unified flour (78-80% extraction, Protein 10.36%, Ash 0.59%) containing 0%, 0.3%, 0.6%, 0.9%, 1.2% and 1.5% (wt/wt on a flour basis) for all three types of salt, using a mixing bowl of 300 g. The mixing properties were analyzed by the constant flour weight procedure as suggested by the AACC official method 54-21.02. All analyses were performed in duplicates.

1. Determination of flour moisture content

The moisture content of flour was determined according to the AACC official method 44-15.02 and was performed in triplicates. The weight of flour used in the farinograph was standardized to 300 g based on 14% moisture content. Therefore, the moisture content of flour was calculated to adjust for weight. Two grams of flour were weighed on a digital balance in pre-weighed aluminum moisture dishes. Dishes were then introduced partially covered into a forced draft oven at 100°C for one hour. After drying, they were covered and cooled in a desiccator to room temperature for weighing. Moisture content was then calculated as percent (%) moisture using the following formula:

$$\frac{\text{Wt(g)original sample - Wt(g)sample after drying}}{\text{Wt(g)original sample}} \times 100$$

2. Farinograph procedure:

The thermostat and circulating pump were switched on prior to all analyses and the temperature was fixed at 30°C. Around 304 g of unified flour were weighed using a digital balance (SB 16001; Mettler Toledo, Switzerland) and placed in the mixing bowl (Sigma Mixer S 300, Farinograph-E, Brabender® GmbH & Co. KG, Germany). Salts were weighed and added to flour according to the flour weight. The large burette was filled with distilled water and all air bubbles were removed before running a sample. All commands were performed from the Farinograph (Farinograph-E, Brabender® GmbH & Co. KG, Germany) software on the computer linked to the machine. Water was added to the right front corner of the bowl from the burette to a volume of expected flour absorption and the dough consistency was centered on 500 ± 20 Brabender Units (BU). Several titrations were performed to obtain the correct consistency depending on the type of salt used and their respective levels. The duration of the test was fixed to 20 min per sample and replicate. Several parameters were obtained from the software for analysis. These include the dough development time, dough stability, mixing tolerance index and time to breakdown.

D. Sensory Evaluation

1. Hedonic evaluation

A consumer acceptability test was conducted to evaluate the experimental bread samples at the sensory laboratory of the Nutrition and Food Science department at AUB.

a. Panelists

Seventy two panelists (27 males and 45 females, age range: 18 – 40) were recruited by direct approach to take part in the acceptability test based on their willingness to participate and their frequency of consumption of Arabic bread. Panelists who never consumed Arabic bread or who consumed it very rarely i.e. once per month, were excluded from the study for the simple reason that they might not be familiar with the product. The selected panelists were mainly students and faculty members from AUB.

b. Acceptability testing

The panelists evaluated the 16 samples in three sessions over a period of three days in individual booths equipped with daylight. Six different samples were assessed during the first session and five samples during the second and third sessions. The hedonic test was administered using the Compusense-at hand® sensory evaluation software.

i. Sample preparation

Bread samples were cut into uniform rectangular pieces, with dimensions of 5 cm for length and 2 cm for width, with kitchen scissors and the two layers were placed in covered transparent sensory cups labeled with three-digit random numbers. The presentation order of the samples was randomized and counterbalanced based on William's design for 6 and 5 samples respectively, as generated by the software. Sample preparation was conducted one day before serving and labeled cups were stored in the refrigerator at +4°C. They were then taken out from the refrigerator 15 min before the start of the test on the day of evaluation.

ii. Evaluation

Panelists were instructed to rinse their mouths with water before and after each sample to cleanse their palate. They were asked to taste the bread samples in the order indicated and to rate the attributes of overall acceptability, acceptability of appearance, color, odor, taste, saltiness and texture on the 9-point hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely). A just-about-right scale was also included in the questionnaire to determine how panelists felt about the saltiness of the samples. This provides information on the compatibility of the relevant salt level with the optimal acceptability level for saltiness. Panelists were therefore asked to rate the saltiness of the samples using a 7-point scale, with 1 being "too low", 4 "just-about-right" and 7 "too high".

2. Difference tests

Because acceptability tests do not discriminate between the samples, it was important to carry out a two-stage difference test. The sensory tests were administered at the sensory laboratory of the Nutrition and Food Science department at AUB.

a. 3-Alternative forced choice test

A 3-Alternative Forced Choice (3-AFC) test was first carried out to assess the difference in saltiness between breads produced with 1.2% and 0.9% NaCl, and 0.9% and 0.6% respectively. The 0.9% was chosen as a standard/control due to its high acceptability level in the previous stage and its compatibility with salt levels used in the local market (Nathalie Barakat, MSc. Thesis, AUB, June 2015). The 3-AFC method in sensory evaluation is often referred to as a "directional triangle test", where the panelist is presented with three samples (two are the same and the one is different) and is asked to indicate the sample that is "higher or lower" in a specific sensory attribute (Lawless & Heymann, 2010). In this case, the panelist was asked to indicate the saltiest bread sample.

i. Panelists

Thirty panelists (15 males and 15 females) were recruited by direct approach to take part in the study based on their willingness to participate and their consumption frequency of Arabic bread. The panelists who agreed to be involved were mainly students and faculty members from AUB.

ii. Sample preparation

Two hours before evaluation, bread samples were removed from the freezer, thawed, cut into uniform rectangular pieces and placed in plastic cups labeled with 3-digit random numbers.

iii. Testing

The 3-AFC testing was carried out over one session in individual booths equipped with daylight lighting. Presentation order was randomized and counterbalanced over sessions and panelists according to the design suggested by MacFie and Bratchell (1989). Participants were asked to evaluate the coded samples in the sequence presented from left to right and to circle the saltiest sample on the ballot sheets provided. They were also instructed to rinse their mouths with mineral water before and between samples to avoid any carry-over effects.

b. Triangle test

A series of triangle tests were conducted between experimental breads containing 0.9% NaCl and 0.6, 0.9 and 1.2% of each of the KCl (30% NaCl substitution) and agglomerated NaCl (Ag-NaCl), allowing the participants to make 6 different comparisons. In this method, the panelist was presented with three samples (two are the same and the one is different) and instructed to indicate the sample that is different from the other two. The objective for administering the triangle test was to determine if any difference was perceived between the bread samples with different salt levels.

i. Panelists

Twenty-nine panelists (13 males and 16 females) were recruited by direct approach to take part in the study based on their willingness to participate and their consumption frequency of Arabic bread. The panelists were mainly students and faculty members from AUB.

ii. Sample preparation

Bread samples were thawed, cut into uniform rectangular pieces, as described above, and placed in covered plastic cups coded with 3-digit random numbers.

iii. Testing

The series of triangle tests were carried out over two sessions on two different days, allowing the panelist to make three comparisons per session. Presentation order was randomized and counterbalanced over sessions and panelists according to the design suggested by MacFie and Bratchell (1989). Participants were asked to evaluate the coded samples in the sequence presented from left to right and to circle the odd sample on the ballot sheets provided. They were also instructed to rinse their mouths with mineral water before and between samples to avoid any carry-over effects.

3. Descriptive analysis

a. Panelists

A quantitative descriptive analysis was performed to further characterize the differences with trained sensory judges rather than with naïve consumers, and to create a sensory profile for the experimental bread samples. Twelve female judges (age range: 21-36), who are familiar with Arabic bread and its sensory characteristics, were recruited from the American University of Beirut based on their willingness to participate and time availability. They were not informed about the nature of the project or about the different treatments.

b. Training sessions

Panelists were trained in the Nutrition and Food Science sensory laboratory at the American University of Beirut over six 1-hour sessions. The training revolved around tasting experimental and commercial Arabic bread samples, discussing their sensory characteristics and developing adequate sensory attributes along with their definitions according to appearance, odor, flavor, texture/mouthfeel, and aftertaste. The judges' performance was evaluated during these training sessions. A final list of 16 attributes was agreed upon along with their definitions, anchor words and reference standards as summarized in Table 4.

c. Evaluation sessions

Nine evaluation sessions (20 min each) were held over a period of five days. The trained panelists were instructed to attend two tasting sessions per day: one morning and one afternoon tasting to prevent sensory fatigue. These sessions took place in the booth area of the sensory laboratory of the Nutrition and Food Science department at the American University of Beirut.

i. Sample preparation:

Breads were thawed and cut into triangular slices, with side lengths of 5 cm × 5 cm, on the same day of the evaluation sessions. Samples were presented to panelists in covered plastic cups coded with 3-digit random numbers.

ii. Descriptive analysis testing

Judges were seated in separated booths equipped with daylight and rated the intensity of the formulated attributes on a 15-cm unstructured line scale using the Compusense at-hand® sensory evaluation software. The bread samples were assessed in triplicate evaluations (3 sessions per replicate) with all 16 samples served within each replicate. Five samples were administered in sessions 1 2, 4, 5, 7 and 8 and 6 samples in sessions 3, 6 and 9. Panelists were asked to rinse their mouths with water before and between samples. The presentation order of the samples was randomized and counterbalanced based on William's design for 16 samples as generated by the software. Participants were provided with a monetary sum of 75,000 L.L at the end of the study as compensation for their participation.

Table 4. Terms used in the descriptive analysis of Arabic bread.

Attribute	Definition as worded on score sheet	Anchor words(low-high)
Appearance		
Crust color	Color ranging from creamy white to pale yellow (front layer)	Creamy white-Pale yellow
Smoothness of surface	Absence of bumps on the surface of the front (white) layer.	Bumpy-Smooth
Crumb porosity	Amount/size of pores (cells) on the inside of the back (brownish) layer.	Not at all-Very
Odor		
Yeasty	Odor of yeast. Assessed by opening bread sample and by smelling on the inside[1].	Not at all-Very
Texture/Mouthfeel		
Rollability	Ability of bread sample (both layers) to fold and roll.	Cracks upon rolling-Rollable
Masticatory hardness	Force required to compress the sample upon biting the rolled layers of bread with incisors	Very soft-Very hard
Cohesiveness of mass	The degree to which the sample holds together in a mass after 3 chews.	Loose mass-Compact mass
Resistance to chewing	Number of times required to chew sample into small pieces.	Not at all-Very
Moistness	Sensation caused by the amount of water extracted from sample upon chewing 3 times.	Not at all-Very
Flavor		
Saltiness	Taste elicited by table salt	Not at all-Very
Sweetness	Taste elicited by sugar (sucrose)	Not at all-Very
Yeasty	The flavor associated with natural yeast as a leavening agent	Not at all-Very
Bitterness	Taste elicited by caffeine	Not at all-Very
Aftertaste		
Sweet	Aftertaste elicited by sucrose	Not at all-Very
Salty	Aftertaste elicited by table salt	Not at all-Very
Bitter	Aftertaste elicited by caffeine	Not at all- Very

[1] Dough pieces, prepared by mixing flour (Golden Medal, Emirates Grain Products Company LLC – Sharjah, UAE) and yeast (DCL yeast Ltd., UK) in mineral water (Rim, bottled at source by Rim Natural Spring Mineral Water SAL – Mount Sannine, Lebanon

4. Determination of equivalent saltiness by magnitude estimation

Implementing a sodium reduction strategy usually results in a loss of taste in the product. It is therefore important to assess the salting potency of the different salt substitutes in Arabic bread, by determining the equivalent saltiness of these replacers relative to sodium chloride using the magnitude estimation method.

a. <u>Panelists</u>

Ten female participants (age range: 21 – 36) were recruited based on their interest in the study, time availability and use of product. Selected subjects were mainly graduate students who are familiar with sensory practices and faculty members from AUB.

b. <u>Training sessions</u>

Panelists were trained in the Sensory Laboratory of the Nutrition and Food Science department at the American University of Beirut over five 1-hour sessions. The training aimed at developing the quantitative skills of the participants. These sessions included quantitative estimation exercises (proportion of shaded area in geometric shapes and length of lines relative to a standard), low-salt solution ranking and saltiness intensity ratings of salt solutions and bread samples using the magnitude estimation scale relative to a reference sample with a standard salt level (bread with 0.9% NaCl), as determined by the hedonic evaluation and compatibility of salt level with current levels in the marketplace (Nathalie Barakat, M.Sc. thesis, AUB, June 2015).

c. Evaluation sessions

The trained judges were asked to perform a total of six evaluation sessions (10 – 15 min each) held over three days, therefore attending two sessions per day separated by a minimum of two hours. These sessions took place in the booth area of the sensory laboratory of the Nutrition and Food Science department at the American University of Beirut.

i. Sample preparation

Bread samples were thawed and cut into triangular slices with side lengths of 5 cm × 5 cm × 5 cm, on the same day of the evaluation sessions. Samples were presented to panelists in covered plastic cups coded with 3-digit random numbers.

ii. Magnitude estimation testing

Judges were instructed to numerically rate the saltiness of the experimental bread samples relative to a reference sample with a value of 100 (0.9% NaCl). For example, if a sample was perceived twice as salty as the reference, a value of 200 should be assigned to it; if half as salty, a rating of 50 should be given. This test was administered using the Compusense at-hand® sensory evaluation software. The bread samples were assessed in duplicate evaluations (3 sessions per replicate) with all 15 samples served within each replicate. Panelists were asked to rinse their mouths with water before starting and between samples. Five samples were administered in each evaluation session and the presentation order of the samples was randomized and counterbalanced based on William's design for 15 samples as generated by the software.

d. Determination of equivalent saltiness

To determine the equivalent saltiness of salt replacers relative to sodium chloride, the "Power Function" was obtained for all levels of NaCl, NaCl-KCl and agglomerated NaCl. As stated earlier, the Power Function is defined as:

$$S = a.C^n$$

where S is the sensation perceived, C the concentration of the stimulus, a the antilog of the y intercept of the linear function and n the slope of the linear function. Magnitude estimates and salt concentrations were transformed into logarithms for normalization of data purposes (De Souza et al., 2011). The logarithmic values of concentration (in %) for NaCl and its substitutes (NaCl-KCl and Ag-NaCl) were graphically plotted against the logarithmic values of magnitude estimates for perceived stimuli. Resulting points were used to perform linear regressions for NaCl and the other salt substitutes, and equations corresponding to the trend line were determined. From the power function of NaCl, the different substitutes and the "ideal" concentration of NaCl in bread (0.9%), the equivalent concentration of sodium chloride substitute was mathematically estimated, as described by previous studies (De Souza et al., 2011).

E. Statistical Analysis

Analysis of variance using the GLM procedure of SPSS statistics for windows software (version 23, IBM Corporation, Armonk, NY, USA) was performed to assess panelist performance (ability to discriminate among the samples, reproducibility, and concept alignment) during panel training, and to assess the significance of the farinograph variables and sensory differences among the experimental samples in the evaluation sessions. In the sensory model for the descriptive sensory data, the response variable was the sensory attribute of the samples. The factors in the model were type of salt (NaCl, NaCl-KCl and Ag-NaCl), level of salt (1.5%, 1.2%, 0.9%, 0.6% and 0.3%), panelist, replicate and their two-way interactions. Panelist was included as random effect and type, level and replicate were fixed effects in the statistical model. Panelist was not included in the farinograph analysis model. Moreover, the sensory acceptability model did not include replicate. Significant means for the sensory and farinograph analyses were separated by Tukey's honestly significant difference and by Dunnett's test to compare all treatments with the 0% salt treatment. Significance was pre-established at $\alpha < 0.05$. Moreover, principal components analysis was performed using the 30 means (3 types × 5 levels × 2 replicates), obtained from descriptive analysis, to extract the main factors that determine relationships among several sensory attributes and differences among samples in the design.

CHAPTER IV

RESULTS AND DISCUSSION

A. Chemical Analysis

1. Sodium and potassium determination

Results of the chemical analyses are presented in Table 5.

The moisture contents of the experimental breads ranged between 24.10 and 29.62%. The results of the chemical analysis for sodium confirm and support the salt levels added during bread processing. As expected, at the same levels, bread samples prepared with Ag-NaCl contain more sodium than samples prepared with NaCl or NaCl-KCl. Breads prepared with NaCl and Ag-NaCl provide on average 180 mg of potassium per 100g regardless of the salt level, while they would supply 300 mg per 100g when a 30% Na substitution with KCl is implemented.

B. Empirical Rheology of Dough

The results of the mixing properties of dough recorded by the farinograph are displayed in Tables 6, 7 and 8. As summarized in Table 6, type of salt had a significant effect on WA ($p<0.01$) and dough stability ($p<0.05$) while level of salt had a significant effect on dough stability ($p<0.0001$), time to breakdown (TTB), mixing tolerance index (MTI) and WA ($p<0.01$). There were no significant differences between the replicates on all variables. The type × level interaction had a significant effect on TTB and MTI ($p<0.01$); the type × replicate interaction showed a significant difference on MTI ($p<0.05$)

Table 5. Sodium, potassium and moisture contents of the experimental Arabic bread samples.

Chemical Variables	Type of salt														
	NaCl					NaCl-KCl					Ag-NaCl				
	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%
Sodium[a]	0.10	0.19	0.29	0.38	0.47	0.07	0.12	0.19	0.26	0.30	0.10	0.21	0.31	0.41	0.51
NaCl[b] (%)	0.25	0.48	0.74	0.97	1.2	0.17	0.31	0.49	0.66	0.77	0.27	0.53	0.78	1.04	1.30
Potassium[a]	0.21	0.20	0.20	0.18	0.18	0.23	0.25	0.31	0.33	0.37	0.16	0.16	0.18	0.18	0.18
Moisture (%)	27.86	25.15	25.26	24.75	25.21	25.01	26.00	26.54	25.78	28.44	25.01	24.10	29.62	29.40	25.25

[a] Sodium, potassium = g/100g

[b] NaCl = % (g/100g)

Table 6. P-values of the farinograph variables for type, level, replicate and their interactions.

Variable	Type (df = 2)	Level (df = 4)	Replicate (df = 1)	T × L (df = 8)	T × R (df = 2)	L × R (df = 5)
Water Absorption	0.004	0.001	0.580	0.528	0.334	0.623
Consistency	0.168	0.842	0.144	0.291	0.646	0.042
Development Time	0.231	0.146	0.475	0.664	0.921	0.456
Stability	0.021	< 0.0001	0.275	0.161	0.944	0.529
Time to Breakdown	0.907	0.005	0.138	0.009	0.054	0.048
Mixing Tolerance Index	0.060	0.005	0.367	0.001	0.040	0.263

T = Type, L = Level, R = Replicate

Table 7. Least squares means of the farinograph variables for type and salt levels.

Variable	Type of salt			Level of salt				
	NaCl	NaCl-KCl	Ag-NaCl	0.3%	0.6%	0.9%	1.2%	1.5%
Water Absorption	57.43[a]	56.91[b]	57.56[a]	58.05[a]	57.48[ab]	57.15[bc]	57.07[bc]	56.75[c]
Consistency	517.10	519.40	514.80	517.83	516.33	515.50	518.33	517.50
Development Time	1.80	1.80	2.00	1.70	1.90	1.80	1.90	2.00
Stability	5.87[ab]	5.15[b]	6.18[a]	3.33[c]	4.42[bc]	5.57[b]	7.22[a]	8.13[a]
Time to Breakdown	3.24	3.20	3.26	2.9[c]	3.05[bc]	3.33[ab]	3.37[a]	3.52[ab]
Mixing Tolerance Index	63.60	63.80	61.10	67.33[a]	66.17[a]	64.17[abc]	59.33[bc]	57.17[c]

[a,b,c] Means with different letters are significantly different ($p<0.05$)

Table 8. Least squares means of the farinograph variables for type × level interaction.

Variable	Type of Salt														
	NaCl					NaCl-KCl					Ag-NaCl				
	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%
WA	58.00	57.50	57.40	57.30	57.00	57.70	57.30	56.50	56.60	56.60	58.50	57.70	57.60	57.30	56.70
DT	1.80	1.70	1.80	1.70	2.00	2.10	1.70	1.70	2.10	2.10	1.70	1.90	1.90	2.10	2.20
STAB	3.50	5.10	5.80	7.00	8.10	3.40	4.00	4.10	6.60	7.70	3.20	4.20	6.80	8.20	8.70
TTB	3.25[ab]	3.05[ab]	3.50[ab]	3.45[ab]	2.95[ab]	2.90[ab]	3.00[ab]	3.40[ab]	3.45[ab]	3.25[ab]	2.55[b]	3.10[ab]	3.10[ab]	3.65[ab]	3.90[a]
MTI	59.50[bc]	60.50[b]	65.50[ab]	60.00[abc]	58.00[bc]	63.50[ab]	66.00[ab]	65.00[ab]	61.50[abc]	70.50[ab]	79.00[a]	72.00[ab]	62.00[abc]	56.50[bc]	43.00[c]

[a,b,c] Means with different letters are significantly different ($p<0.05$)

WA = Water Absorption, DT = Development Time, STAB = Stability, TTB = Time to Breakdown, MTI = Mixing Tolerance Index and the level × replicate interaction had a significant effect on consistency and TTB ($p<0.05$).

Dough mixed with 30% substituted KCl had a significantly lower WA than dough mixed with NaCl and Ag-NaCl (Table 7), that showed no differences between each other. Kaur et al. (2011) reported that a NaCl-KCl proportion of 75:25 led to a decrease in WA when compared with the control (100% NaCl). In this work, stability was significantly higher in the dough mixed with Ag-NaCl than the dough containing KCl (Table 7), but no differences were observed between dough with NaCl and NaCl-KCl. In agreement with Kaur et al. (2011), development time, TTB and MTI did not differ significantly between the salts.

Dough with 0.3% added salt obtained the highest WA value and was significantly different from dough containing 0.9%, 1.2% and 1.5% salt (Table 7). These findings were consistent with the results of previous work that showed that decreasing salt levels from 4% to 0% significantly increased WA (Beck et al., 2012a). Moreover, an addition of 1.5% NaCl to flour (wt/wt) was shown to decrease WA by 1.4% (Farahnaky & Hill, 2007). Adding salt to the dough seems to increase protein association by the means of ionic, hydrophobic and hydrogen bonds that cause a decrease in WA (Belz et al., 2012). It is widely accepted that the addition of salt increases dough stability (Beck et al., 2012a; Farahnaky & Hill, 2007) whereby dough containing high salt levels (1.5% and 1.2%) exhibited significantly higher stability than the remaining levels. Salt-reduced doughs tend to be relatively firm at the beginning of the mixing process but can easily become over-mixed resulting in a less stable and weak dough. As expected, TTB and MTI are directly related to added salt levels and dough stability. Our results have shown that a salt level of

1.5% (wt/wt) significantly increased the time to breakdown of dough when compared with 0.6% and 0.3% and that the latter treatments obtained significantly higher values on MTI. Salt enhances the strength of the dough and the mixing time can last longer with minimal degradation of the gluten structure. As a matter of fact, when the stability is low, the dough will start to break down early and will lead to a higher degree of softening (Bassett et al., 2014). MTI is an indication of the degree of softening during mixing. Generally, dough with low MTI is known to possess good tolerance towards mixing. In other words, the weaker the dough the higher, the MTI value. However, even with the addition of salt, the obtained dough was quite weak, probably attributed to the type of flour used. The flour used in Arabic bread processing has medium protein quality, and the resulting dough can be more difficult to handle than ones made from flour with high protein quality. Unlike results obtained in other studies (Farahnaky & Hill, 2007), neither type or level of salt induced any changes in the dough development time. Belz et al. (2012) reported that, with increasing salt levels, less water is available for the development of the gluten network, therefore increasing dough development time.

Dough mixed with 1.5% Ag-NaCl (Table 8) showed the highest value for TTB and was significantly different from dough with 0.3% Ag-NaCl that displayed the lowest value. A clear decreasing trend can be observed with decreasing salt levels for Ag-NaCl, confirming the strengthening effect of salt on dough. However, this trend did not seem to be very clear for the NaCl and NaCl-KCl treatments despite the absence of significant differences between them. Furthermore, dough mixed with Ag-NaCl displayed a trend for higher values than dough mixed with regular NaCl at high levels (1.5% and 1.2%), but lower values at low levels (0.3%), which might indicate that Ag-NaCl does not dissolve completely at low levels during dough mixing. The results of MTI negatively correlated with those of TTB, as dough with 0.3% Ag-NaCl had a significantly higher MTI than dough with 1.2% and 1.5% Ag-NaCl (Table 8). This sample was also significantly different from 1.5%, 0.6% and 0.3% NaCl. However, even if these samples were different, the means for all samples were not that different except for 0.3% Ag-NaCl and 1.5% Ag-NaCl. Moreover in the present work there was a noticeable decreasing trend in stability with decreasing salt levels regardless of the type of salt used, although not significantly. In addition, Kaur et al. (2011) reported that 25% and 50% NaCl substitution with KCl significantly improved the stability of dough, which was not the case in this work. Our results showed that a 30% KCl replacement slightly increased the stability of dough for each level when compared to NaCl values, but overall, KCl does not seem to have much influence on dough stability.

The Dunnett's test compared the mixing properties of dough with 0% salt with all the other samples on all farinograph variables and the table is shown in Appendix VI. As expected, dough with no added salt had the highest WA and was different from all samples except for 0.3% NaCl and Ag-NaCl. It had a low stability and was significantly different from the 0.9% NaCl and Ag-NaCl treatments and from the 1.2% and 1.5% levels for all three types of salt, therefore confirming the strenghtening effect of salt on the dough properties. There were no differences between all samples on development time and TTB. Dough without salt obtained a high MTI and was only different from dough with 0.3% and 1.5% Ag-NaCl, indicating that the dough is already weak with or without the addition of salt.

C. Hedonic Evaluation

1. Acceptability ratings

The results of acceptability tests are summarized in Tables 9, 10 and 11. There was a significant difference between the panelists on all acceptability attributes (Table 9) of the Arabic bread samples ($p<0.0001$). Type of salt had a significant effect on taste ($p<0.01$), appearance, color and saltiness ($p<0.05$). As expected, level of salt seemed to affect consumer acceptability of bread on all attributes (Table 9). Concerning the interactions, there were no significant differences for P × L, but was not the case for both P × T and T × L which were significant on all acceptability attributes ($p<0.05$).

Bread samples prepared with NaCl scored the highest means for appearance, color, taste and saltiness (Table 10), followed directly by those prepared with Ag-NaCl. These samples showed no significant differences between the two treatments. The NaCl-KCl treatment scored the lowest means for aforementioned acceptability variables and was significantly different from the other two treatments. However, the different salt treatments did not seem to affect the overall acceptability, the odor and the texture of the experimental bread samples. Although not significant, NaCl and Ag-NaCl treatments received higher ratings for these three attributes than the NaCl-KCl treatment.

As for the different levels used (Table 10), results showed that bread with 0.9% salt received the highest ratings for all acceptability attributes, followed by those with 1.2% and 1.5% added salt. These three levels were not significantly different from each other except on appearance that showed differences in the liking between 0.9% and 1.5%, with higher values for the former, but not between 0.9% and 1.2% salt.

Table 9. P-values of acceptability attributes for panelist, type of salt, level of salt and their two-way interaction.

Acceptability Attribute	Panelist (df = 71)	Type (df = 2)	Level (df = 5)	P × T (df = 142)	P × L (df = 284)	T × L (df = 8)
Overall acceptability	< 0.0001	0.063	< 0.0001	0.015	0.680	0.001
Appearance	< 0.0001	0.039	< 0.0001	0.022	0.775	0.010
Color	< 0.0001	0.024	< 0.0001	0.001	0.752	0.019
Odor	< 0.0001	0.593	0.001	0.001	0.501	< 0.0001
Taste	< 0.0001	0.005	< 0.0001	0.002	0.298	0.003
Saltiness	< 0.0001	0.031	< 0.0001	< 0.0001	0.106	0.004
Texture	< 0.0001	0.120	< 0.0001	0.025	0.453	0.004

P = Panelist, T = Type, L = Level

Table 10. Least squares means of the acceptability scores of Arabic bread samples for the three types of salt and the five salt levels.

Acceptability Attribute	Type of salt			Level of salt				
	NaCl	NaCl-KCl	Ag-NaCl	1.5%	1.2%	0.9%	0.6%	0.3%
Overall acceptability	5.94[a]	5.63[a]	5.83[a]	5.82[abc]	5.97[ab]	6.20[a]	5.60[bc]	5.43[c]
Appearance	6.18[a]	5.85[b]	6.08[ab]	5.97[bc]	6.22[ab]	6.43[a]	5.93[bc]	5.63[c]
Color	6.28[a]	5.93[b]	6.21[a]	6.21[ab]	6.19[ab]	6.46[a]	6.07[bc]	5.75[c]
Odor	6.23[a]	6.14[a]	6.27[a]	6.23[ab]	6.21[ab]	6.53[a]	6.12[c]	5.98[c]
Taste	5.89[a]	5.41[b]	5.76[a]	5.81[a]	5.92[a]	5.95[a]	5.62[a]	5.13[b]
Saltiness	5.61[a]	5.26[b]	5.57[a]	5.75[a]	5.74[a]	5.75[a]	5.32[b]	4.82[c]
Texture	5.71[a]	5.41[a]	5.64[a]	5.55[ab]	5.85[ab]	6.00[a]	5.51[b]	5.02[c]

[a,b,c] Means with different letters are significantly different ($p<0.05$)

Table 11. Least squares means of the acceptability scores of Arabic bread samples for the type × level interaction.

Attribute	Type of salt														
	NaCl					NaCl-KCl					Ag-NaCl				
	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%
Overall	5.86^{abc}	5.83^{abc}	6.26^{ab}	5.82^{abc}	5.94^{ab}	5.03^{c}	5.01^{c}	6.36^{a}	5.88^{abc}	5.89^{abc}	5.40^{bc}	5.96^{ab}	5.97^{ab}	6.21^{ab}	5.63^{abcd}
Appearance	5.90^{abcd}	6.10^{abcd}	6.71^{a}	6.01^{abcd}	6.17^{abcd}	5.32^{d}	5.43^{cd}	6.51^{ab}	6.19^{abcd}	5.79^{bcd}	5.68^{bcd}	6.25^{abc}	6.06^{abcd}	6.44^{ab}	5.94^{abcd}
Color	6.06^{abc}	6.28^{ab}	6.68^{a}	5.93^{abc}	6.43^{ab}	5.36^{c}	5.67^{bc}	6.50^{abc}	6.08^{abc}	6.01^{abc}	5.83^{abc}	6.28^{abc}	6.21^{abc}	6.54^{ab}	6.18^{abc}
Odor	6.17^{abc}	6.50^{ab}	6.64^{a}	5.81^{bc}	6.01^{abc}	5.76^{bc}	5.71^{c}	6.50^{ab}	6.28^{abc}	6.47^{abc}	6.00^{abc}	6.15^{abc}	6.44^{abc}	6.54^{ab}	6.19^{abc}
Taste	5.78^{ab}	6.07^{a}	6.07^{a}	5.65^{ab}	5.86^{ab}	4.60^{c}	5.04^{bc}	5.83^{ab}	5.88^{ab}	5.72^{ab}	5.00^{bc}	5.74^{ab}	5.96^{ab}	6.24^{a}	5.86^{ab}
Saltiness	5.33^{abcd}	5.67^{ab}	5.94^{a}	5.47^{abc}	5.63^{ab}	4.44^{d}	4.85^{bcd}	5.60^{abc}	5.61^{abc}	5.78^{a}	4.69^{cd}	5.46^{abc}	5.71^{ab}	6.13^{a}	5.86^{a}
Texture	5.65^{abc}	5.57^{abc}	6.11^{a}	5.60^{abc}	5.64^{abc}	4.68^{c}	4.93^{bc}	5.97^{ab}	5.93^{ab}	5.51^{abc}	4.72^{c}	6.04^{a}	5.93^{ab}	6.01^{a}	5.50^{abc}
Saltiness JAR	3.18^{defg}	3.42^{bcde}	3.63^{abcd}	3.72^{abcd}	4.17^{a}	2.86^{fg}	3.07^{efg}	3.38^{cdef}	3.43^{bcde}	3.90^{abc}	2.81^{g}	3.28^{defg}	3.40^{bcdef}	3.93^{ab}	4.17^{a}

^{a,b,c} Means with letters are significantly different ($p<0.05$)

As for the different levels used (Table 10), results showed that bread with 0.9% salt received the highest ratings for all acceptability attributes, followed by those with 1.2% and 1.5% added salt. These three levels were not significantly different from each other except on appearance that showed differences in the liking between 0.9% and 1.5%, with higher values for the former, but not between 0.9% and 1.2% salt. Additionally, low salt levels i.e. 0.6% and 0.3% were not significantly different from each other on overall acceptability, appearance, color and odor, but were different on taste, saltiness and texture. Furthermore, no differences were observed between breads containing 0.3%, 0.6% and 1.5% on overall acceptability and appearance and there were no differences between 0.6%, 1.2% and 1.5% on color and texture. Low salt levels seem to affect consumer acceptability of bread (Liem et al., 2011).

Concerning the T×L interaction (Table 11), results showed that breads produced with 0.9% NaCl and 1.2% Ag-NaCl received the highest acceptability ratings for all attributes and were not different from each other. Along with the 0.9% NaCl and 1.2% Ag-NaCl treatments, the 0.9% NaCl-KCl treatment had high ratings for overall acceptability, appearance, color and odor; the 0.6% NaCl sample obtained high ratings for taste; the 1.5% Ag-NaCl and NaCl-KCl treatments received high ratings for saltiness; and the 0.6% Ag-NaCl high score for texture. The 0.9% NaCl and 1.2% Ag-NaCl samples were significantly different from levels 0.3% and 0.6% NaCl-KCl on all acceptability variables, and different from 0.3% Ag-NaCl on all attributes except for odor and color.

The Dunnett’s test compared the acceptability ratings of bread containing 0% salt with all the other samples and the table is found in Appendix VII. Bread without salt showed significantly lower scores from the 0.9% NaCl and 1.2% Ag-NaCl treatments on all attributes except odor. Bread produced with 0.9% NaCl-KCl scored higher on overall acceptability, appearance, color and texture, while the 1.2% NaCl-KCl treatment on color and texture and the 1.5% NaCl-KCl sample on saltiness only. Bread with 0.6% NaCl was more acceptable on taste and saltiness; the 1.2% NaCl sample on texture and the 1.5% NaCl treatment on appearance and texture. As for bread produced with Ag-NaCl, the 0.6% sample scored higher on appearance and texture; the 0.9% sample on saltiness and texture and the 1.5% treatment on saltiness only.

Overall, no major differences were observed between appearance, odor and color except for low salt levels of the KCl treatment. However, incorporating a small percentage of KCl (0.27%) enhances acceptability of bread. Wyatt and Ronan (1982) showed that bread produced with 0.75% NaCl-KCl (1:1 ratio) received the highest mean for overall desirability (6.26) when rated on the 9-point hedonic scale. This score was significantly higher than the control bread (1% NaCl wt/wt) but when compared to our study, the score obtained for bread with 0.9% NaCl-KCl on overall acceptability was not significantly different from the 0.9% NaCl treatment. It is also interesting to note that the percentage of KCl in their experimental bread was nearly similar to the one in the present work, perhaps suggesting an optimal percentage of that salt in bread. Nevertheless, overall acceptability ratings in this work are not the only index but they were considered with the multitude of other acceptability variables. Interestingly, reducing NaCl levels, in the NaCl treatment, from 1.5% to 0.3% did not affect consumer acceptability of bread samples on all attributes. However, Lynch et al. (2009) showed that reducing NaCl levels from 1.2% to 0.6% is achievable with no significant effect on liking of bread flavor, but that a further reduction would significantly influence the flavor of bread. On the other hand, bread with 0.4% NaCl still had acceptable sensory properties (Belz et al., 2012). Other studies assessed consumer acceptability and purchase intent of 25% and 30% reduced-Na bread and reported that these reductions did not impact overall acceptability, color, flavor and texture and no differences were perceived when compared with the control (Brinsden et al., 2013; Girgis et al., 2003; La Croix et al., 2015; Saavedra-Garcia, Sosa-Zevallos, Diez-Canseco, Miranda, & Bernabe-Ortiz, 2015). However, these studies did not show how further reductions would affect consumer liking of bread. Comparisons with the 0% salt level**,** in this work, revealed that no major differences were found between the acceptability of bread samples except for 0.6% NaCl, 0.9% NaCl and 1.2% Ag-NaCl. Bread produced without salt was found to have an "insipid taste" (Miller & Hoseney, 2008), but did not seem to interfere much with acceptability ratings in our study, thus the need and plan to conduct descriptive analysis to further characterize these differences with sensory judges rather than naïve consumers. An assessment of Na in breads from bakeries across Lebanon (Barakat, N. AUB M.Sc. thesis, June 2015) showed fluctuations in salt levels of white pita bread ranging from 0.19% to 2.72%, with an average of 1.3%. These findings suggest that Arabic bread consumers may be used to consuming bread with a very wide range of salt levels. Around 24% of the participants enrolled in our study reported to usually consume white pita bread from Bakery A (average NaCl level of 0.2% in above study); 50% from Bakery B (average NaCl level of 0.92%), which could explain why the 0.9% NaCl treatment received the highest acceptability ratings. Around 21% of participants reported to consume Arabic bread from Bakery C (average NaCl level of 2.72%). It is noteworthy to mention that bakery B above enjoys a large market share thus indicating a good reflection of market segmentation in our consumer / panelists sample. It is also interesting to note that bread is usually not consumed alone and that reducing Na up to 50% does not seem to trigger a sodium intake compensation by changing the choice of fillings (Bolhuis et al., 2011).

Our results also showed that decreasing salt levels from a level of 1.5% of each type of salt affects saltiness acceptability of the bread samples for low levels only. As a matter of fact, there seems to be a decreasing trend in the liking of bread with reduced salt levels although not significantly different except for samples produced with 0.3% and 0.6% NaCl-KCl and 0.3% Ag-NaCl. Girgis et al. (2003) reported that the ratings for saltiness acceptability showed a progressive trend towards lower acceptability ratings with Na-reduced bread when compared with the control bread. However, this observed trend was not significant and was applicable for 25% Na-reduced bread unlike the present work.

In general, there does not seem to be universally accepted evidence about the amount of sodium to reduce in bread without affecting taste, consumer acceptability and purchase intent. It is therefore necessary to understand a population's characteristics before implementing a sodium reduction strategy in bread.

2. Just-About-Right ratings

The Just-About-Right scale ratings for the different samples on saltiness are illustrated in Figure 3. High proportions of ratings in the -1 to +1 range indicates an optimal level of taste intensity relative to the liking of panelists while a high percentage of lower and upper ratings indicates low or high intensity relative to the liking of taste respectively.

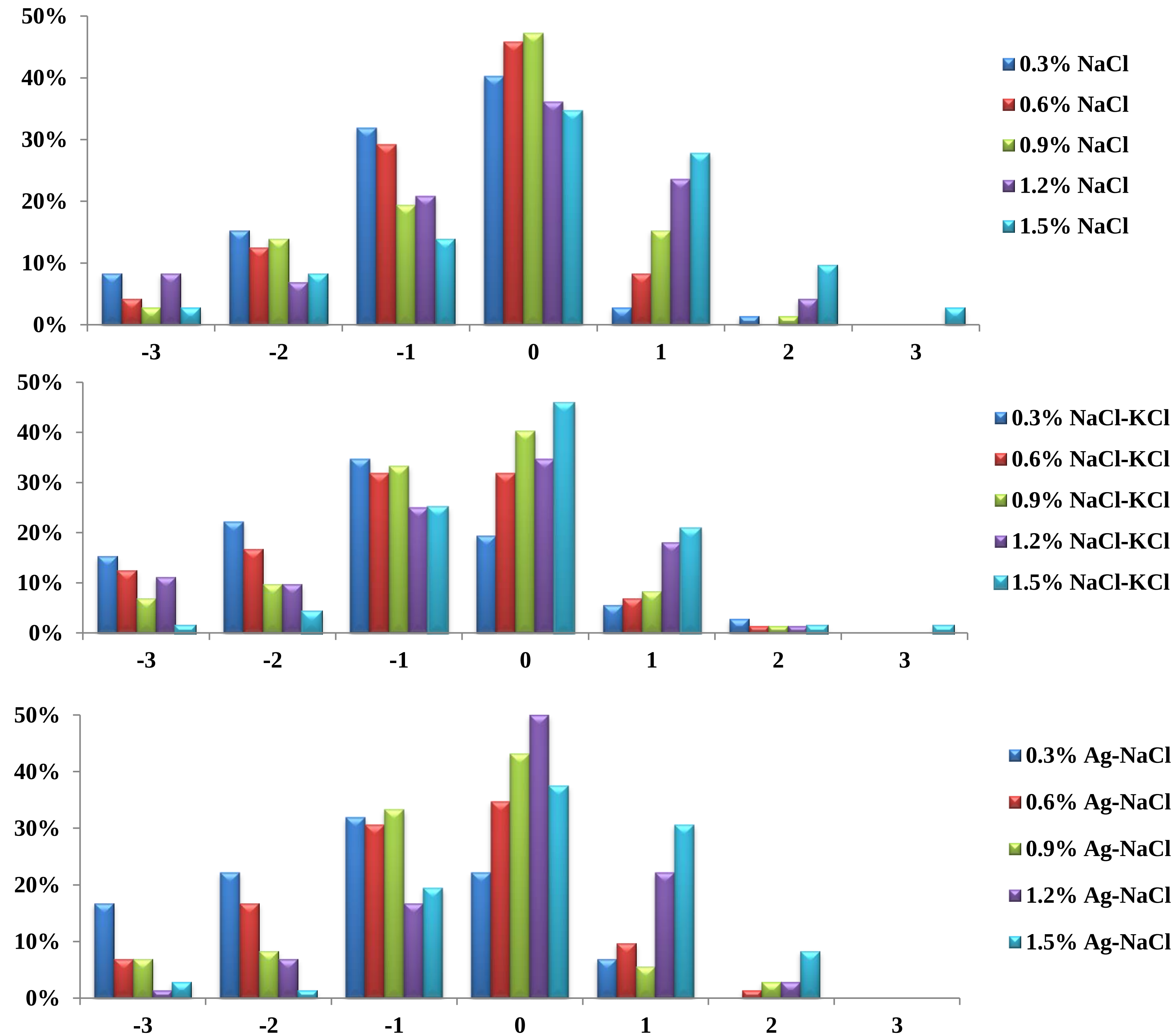


Figure 3. Just-About-Right (JAR) ratings for saltiness for Arabic bread samples produced with NaCl (A), NaCl-KCl (B), and Ag-NaCl (C); -3: Too Little, 0: Just-About-Right, 3: Too Much

Bread with 0.9% NaCl seems to be the best sample in terms of percentage of subjects who found it to have the optimal salty taste to their liking. As for the salt substitutes, bread with 1.5% NaCl-KCl and 1.2% Ag-NaCl were found to have an optimal salty taste. Bread with 0.3% and 0.6% salt (all three types) seemed to have a tilt for higher percentages of participants who gave lower ratings for saltiness (not enough salt for proper liking), while the opposite was true for 1.2% NaCl, 1.5% NaCl and 1.5% Ag-NaCl. The present results support those of saltiness liking. They are also contradictory since the saltiness intensity of Ag-NaCl should, in theory, be higher than regular NaCl for the same percentage, as expected from this type of salt that should deliver a higher saltiness for the same percentage. Moreover, the JAR results summarized in Table 11 support the acceptability ratings. Bread samples produced with high and intermediate salt levels, namely 1.5% of all three treatments, 1.2% NaCl-KCl and Ag-NaCl treatments as well as 0.9% NaCl were significantly different form breads containing low salt levels i.e. 0.3% and 0.6% NaCl-KCl and 0.3% Ag-NaCl. However, JAR scaling incorporates at the same time consumer acceptability and the measurement of attribute intensity (Moskowitz, Muñoz, & Gacula Jr, 2008), which might combine several biases. JAR ratings might be influenced by "cognitive factors" in addition to attribute perception. For example, participants who have enough awareness about salt and its adverse health effects may treat saltiness as a negative attribute (Lawless & Heymann, 2010). JAR scaling also seems to be a challenging task for naïve consumers as several factors should be taken into consideration. Participants should first perceive the attribute intensity in the product then locate their "ideal point" on the scale, and compare the difference between the attribute intensity and ideal point (Li, Hayes, & Ziegler, 2014). Furthermore, this scaling method assumes that a participant has an optimal level of saltiness in bread which may not be relevant if he/she is truly indifferent to variations in saltiness in the product. Lawless and Heymann (2010) reported that the sample portion size also plays an important role when rating an attribute on the JAR scale, suggesting that what seems to be appealing in small bites might not be the case with larger portions of the same sample. As covered earlier, the fact that several samples were assessed, as is usually the case in acceptability tests, might have induced some sensory fatigue and carry-over effects in participants, therefore slightly biasing their responses.

D. Difference tests

The results of the 3-AFC and triangle tests are displayed in Tables 12 and 13.

1. 3-AFC

Bread samples included in this test had a sodium difference of 33% and results (Table 12) demonstrated that participants were able to correctly identify the saltier bread sample when compared to the selected control (0.9% NaCl). Similarly, La Croix et al. (2015) reported that a 30% Na reduction in bread was found to be detected by untrained consumers when testing for a difference in saltiness, while a 10% reduction can remain unnoticed.

Table 12. 3-AFC test results for bread samples produced with 0.6%, 0.9% (control) and 1.2% NaCl.

Comparisons	Number of Correct Responses[a]	Difference[b]
0.6% vs. 0.9% NaCl	22/30	Significant
0.9% vs. 1.2% NaCl	22/30	Significant

[a] Critical number of correct responses: n = 15
[b] Significance for a difference was determined at an α-level of 5%

Although the difference in saltiness was distinguishable by the panelists, these reductions did not adversely affect consumer acceptability of bread, which was also confirmed in our study. Moreover, Mueller et al. (2016) found that a 16% and 23% Na reduction in pizza crust were noted as significantly less salty when administering a 2-AFC test. However, the probability of scoring correctly in the 2-AFC test is higher than in the 3-AFC test, making it easier to discriminate between the samples.

2. Triangle test

Table 13. Triangle test results for bread samples produced with 0.9% NaCl (control) and 0.6%, 0.9% and 1.2% of each of NaCl-KCl and Ag-NaCl treatments.

Comparisons	Type of Salt			
	NaCl-KCl		Agglomerated NaCl	
	Number of CR[a]	Difference[b]	Number of CR[a]	Difference[b]
Control vs. 0.6%	8/29	Not significant	10/29	Not significant
Control vs. 0.9%	12/29	Not significant	17/29	Significant
Control vs. 1.2%	16/29	Significant	17/29	Significant

[a] CR = Correct responses

[b] Significance for a difference was determined at an α-level of 5%; Critical number of correct responses: n = 15.

When tested for a difference at an α-level of 0.05, both the 0.6% and 0.9% of the KCl treatment were perceived as not significantly different from the control (0.9% NaCl), while the 1.2% NaCl-KCl sample was significantly different from the control (Table 13). As for the Ag-NaCl treatment, bread with a salt level of 0.6% was not significantly different from the control, whereas bread with 0.9% and 1.2% were statistically different.

Saavedra-Garcia et al. (2015) showed that rice prepared with 25% substituted KCl was not identifiable when assessed by the triangle test, while the difference with a 33%

replacement was distinguishable. Our results showed that an NaCl replacement of 30% with KCl in bread was not perceived by the panelists and are in agreement with Mueller et al. (2016), who showed that the panel failed to recognize a difference when a 30% KCl replacement was implemented in pizza crust. These differences were observed probably because dough-based products like bread and pizza crust have a more complex matrix than boiled rice. Surprisingly, Mueller et al. (2016) reported that panelists did not perceive a difference when replacing NaCl with Ag-NaCl at the same salt level in pizza crust. When the amount of Ag-NaCl was reduced by 25% and compared with the control (100% NaCl), panelists rated the control as saltier despite the fact that the final salt level in the product was similar to ours (1.09% salt). Their results indicated that the microcrystalline structure of Ag-NaCl does not enhance saltiness, due to a possible loss of functionality during processing. However, the 2-AFC test in the above study, guides the participant with the direction of the difference, whereas the triangle test, like the one conducted in this work, does not indicate the nature or the magnitude of the sensory difference between the samples (Lawless & Heymann, 2010).

E. Descriptive analysis

1. ANOVA

The descriptive analysis results and least squares means are summarized in Tables 14, 15 and 16. As expected, analysis of variance revealed significant differences for panelist ($p<0.05$) for all attributes except for crust color (Table 14). Significant differences were obtained between the types of salt for a few attributes only, namely smoothness of surface, rollability ($p<0.001$), and crust color ($p<0.01$). Differences were also observed

Table 14. F and p-values of descriptive sensory analysis attributes for panelist, type, level, replicate and their interaction for Arabic bread samples.

Descriptor	Panelist (df = 11)	Type (df = 2)	Level (df = 4)	Rep (df = 1)	P×T (df = 22)	P×L (df = 44)	P×R (df = 11)	T×L (df = 8)	T×R (df = 2)	L×R (df = 4)	P×T×L (df = 88)	T×L×R (df = 8)
Crust Color	22.13	6.48**	5.60***	0.10	0.52	0.64	1.10	7.06***	2.00	3.01*	1.45*	0.76
Smoothness of Surface	12.07*	11.11***	3.72*	0.79	0.76	0.96	0.83	3.74***	4.33*	2.56*	1.47*	6.52***
Crumb Porosity	5.42**	1.33	3.17*	1.14	2.27**	1.36	1.01	1.57	1.82	0.54	0.61	1.19
Yeasty Odor	23.56***	2.06	0.59.	0.13	1.91*	0.75	0.98	3.91***	0.67	1.60	0.88	0.59
Rollability	5.88**	9.76***	3.88**	0.11	0.97	0.96	1.54	2.71**	0.94	2.05	1.23	1.63
Masticatory Hardness	12.23**	0.77	1.45	2.22	1.13	1.05	0.80	4.46***	3.40*	3.02*	0.97	1.80
Cohesiveness of Mass	3.51*	1.44	1.79	3.04	1.38	1.11	2.15*	1.09	0.33	1.68	0.83	1.87
Resistance to Chewing	5.26**	0.57	2.17	1.18	1.14	1.36	2.06*	4.84***	3.15*	3.09*	0.81	1.64
Moistness	5.34**	0.49	1.04	0.04	1.21	1.08	1.52	4.10***	0.21	3.32*	0.88	1.05
Saltiness	8.18***	2.55	27.06***	0.20	1.28	1.58*	3.65***	0.82	3.22*	1.51	1.89***	1.18
Sweetness	5.55***	1.45	6.73***	4.03	1.08	2.17***	2.19*	1.30	0.58	0.94	1.31	0.43
Yeasty Flavor	18.13***	2.10	1.84	6.32*	1.79*	0.94	1.51	3.44**	0.28	0.14	0.78	1.44
Bitterness	3.71*	0.36	1.39	0.01	2.07**	1.19	2.85**	0.61	3.50*	2.41	0.79	0.57
Sweet Residual	6.22***	0.55	4.84**	1.27	2.37**	2.47***	3.93***	1.18	0.23	0.12	0.87	0.44
Salty Residual	4.37***	0.54	19.34***	0.39	2.93***	3.13***	6.89***	1.56	3.29*	3.06*	1.18	0.73
Bitter Residual	5.83**	0.90	0.58	0.01	0.70	1.15	4.07***	0.37	5.37**	0.97	1.40*	0.44

P = Panelist, T = Type, L = Level, R = Replicate
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.0001$

Table 15. Least squares means of descriptive sensory attributes for type and level for Arabic bread samples.

	Type			Level				
Descriptor	NaCl	NaCl-KCl	Ag-NaCl	1.5%	1.2%	0.9%	0.6%	0.3%
Crust Color	6.89[a]	5.92[b]	6.33[ab]	6.89[ab]	6.26[abc]	5.90[bc]	7.19[a]	5.65[c]
Smoothness of Surface	7.41[b]	8.89[a]	8.07[b]	8.73[a]	8.18[ab]	7.72[ab]	8.69[a]	7.29[b]
Crumb Porosity	8.28[a]	8.72[a]	8.13[a]	7.91[a]	8.25[a]	8.27[a]	9.17[a]	8.28[a]
Yeasty Odor	5.84[b]	6.55[a]	5.93[ab]	5.94[a]	6.13[a]	6.22[a]	5.93[a]	6.31[a]
Rollability	8.55[b]	9.84[a]	9.64[a]	9.81[a]	9.69[a]	8.66[b]	9.76[a]	8.81[ab]
Masticatory Hardness	6.79[a]	6.57[a]	6.33[a]	6.71[a]	7.12[a]	6.26[a]	6.13[a]	6.58[a]
Cohesiveness of Mass	8.81[a]	9.25[a]	8.72[a]	9.07[a]	9.45[a]	8.71[a]	8.48[a]	8.92[a]
Resistance to Chewing	6.97[a]	6.86[a]	6.62[a]	7.20[a]	7.38[a]	6.17[a]	6.53[a]	6.82[a]
Moistness	7.62[a]	7.81[a]	7.51[a]	7.84[a]	7.48[a]	7.52[a]	8.01[a]	7.38[a]
Saltiness	4.94[ab]	4.60[b]	5.22[a]	6.75[a]	5.86[b]	5.00[c]	3.85[d]	3.15[e]
Sweetness	3.41[a]	3.76[a]	3.55[a]	2.87[b]	3.05[b]	3.33[b]	4.23[a]	4.38[a]
Yeasty Flavor	3.02[b]	3.51[a]	3.25[ab]	3.04[a]	3.25[a]	3.24[a]	3.16[a]	3.61[a]
Bitterness	3.59[a]	3.48[a]	3.33[a]	3.48[a]	3.21[a]	3.59[a]	3.24[a]	3.81[a]
Sweet Residual	2.83[a]	2.94[a]	3.02[a]	2.65[c]	2.57[c]	2.79[bc]	3.20[ab]	3.44[a]
Salty Residual	3.64[a]	3.41[a]	3.56[a]	4.89[a]	4.07[b]	3.34[c]	2.79[d]	2.58[d]
Bitter Residual	3.10[a]	3.17[a]	3.33[a]	3.26[a]	3.01[a]	3.24[a]	3.08[a]	3.41[a]

[a,b,c] Means with different superscripts are significantly different ($p < 0.05$)

Table 16. Least squares means of descriptive sensory attributes for type × level interaction for Arabic bread samples.

Descriptor	Type of Salt														
	NaCl					NaCl-KCl					Ag-NaCl				
	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%
Crust Color	3.57^{e}	8.00^{a}	8.11^{a}	7.41^{a}	7.33^{a}	6.07^{abcd}	5.84^{abcde}	4.66^{cde}	6.75^{abcd}	6.27^{abcd}	7.32^{ab}	7.71^{a}	4.93^{bcde}	4.62^{de}	7.05^{abc}
Smoothness of surface	7.43^{bcd}	7.41^{bcd}	6.44^{cd}	7.51^{bcd}	8.28^{abc}	8.80^{ab}	9.15^{ab}	7.80^{bcd}	8.41^{abc}	10.29^{a}	5.65^{d}	9.50^{ab}	8.93^{ab}	8.63^{abc}	7.62^{bcd}
Crumb Porosity	8.58	8.35	8.72	8.44	7.33	8.53	8.16	10.18	8.13	8.59	7.73	8.30	8.62	8.18	7.82
Yeasty Odor	7.18^{ab}	6.01^{abc}	4.68^{c}	5.40^{bc}	5.95^{abc}	6.07^{abc}	6.15^{abc}	7.77^{a}	6.33^{abc}	6.44^{abc}	5.68^{abc}	5.64^{abc}	6.20^{abc}	6.66^{abc}	5.44^{bc}
Rollability	8.03^{cd}	9.96^{abc}	8.14^{cd}	7.70^{d}	8.92^{abcd}	9.23^{abcd}	9.31^{abcd}	9.05^{abcd}	10.49^{ab}	11.13^{a}	9.17^{abcd}	10.02^{abc}	8.78^{bcd}	10.88^{ab}	9.37^{abcd}
Masticatory Hardness	5.94^{b}	5.20^{b}	6.62^{ab}	9.15^{a}	7.00^{ab}	6.77^{ab}	7.44^{ab}	5.60^{b}	6.68^{ab}	6.34^{b}	7.02^{ab}	5.75^{b}	6.57^{ab}	5.51^{b}	6.80^{ab}
Cohesiveness of Mass	8.56	8.18	8.26	10.04	9.02	9.47	9.23	8.97	9.59	8.98	8.75	8.01	8.90	8.71	9.21
Resistance to Chewing	6.01^{b}	5.80^{b}	6.43^{ab}	9.07^{a}	7.56^{ab}	7.08^{ab}	7.77^{ab}	5.42^{b}	7.21^{ab}	6.81^{ab}	7.36^{ab}	6.03^{b}	6.66^{ab}	5.85^{ab}	7.22^{ab}
Moistness	8.35^{ab}	8.63^{a}	6.97^{ab}	6.33^{b}	7.80^{ab}	6.81^{ab}	7.21^{ab}	3.39^{ab}	8.13^{ab}	8.50^{ab}	6.98^{ab}	8.19^{ab}	7.20^{ab}	7.98^{ab}	7.23^{ab}
Saltiness	3.23	3.67	4.97	6.08	6.76	2.98	4.02	4.38	5.54	6.07	3.23	3.85	5.64	5.97	7.41
Sweetness	4.15	4.24	3.05	2.90	2.72	4.73	3.75	3.81	3.21	3.30	4.25	4.70	3.12	3.05	2.60
Yeasty Flavor	4.15^{a}	2.98^{ab}	2.51^{b}	2.65^{ab}	2.81^{ab}	3.31^{ab}	3.34^{ab}	4.06^{a}	3.28^{ab}	3.54^{ab}	3.38^{ab}	3.15^{ab}	3.13^{ab}	3.82^{ab}	2.78^{ab}
Bitter Flavor	4.30	3.37	4.00	3.15	3.32	3.51	3.32	3.56	3.52	3.50	3.62	3.03	3.41	2.95	3.63
Sweet Residual	3.34	3.28	2.51	2.46	2.55	3.70	3.00	3.15	2.53	2.74	3.29	3.31	2.71	2.72	2.66
Salty Residual	2.58	2.80	3.37	4.58	4.85	2.56	2.81	3.23	3.89	4.54	2.61	2.77	3.43	3.73	5.27
Bitter Residual	3.33	2.91	3.25	3.02	3.00	3.21	3.37	3.08	2.96	3.23	3.70	2.95	3.40	3.06	3.56

^{a,b,c} Means with different superscripts are significantly different ($p < 0.05$)

between the five salt levels for crust color, saltiness, sweetness, salty residual ($p<0.001$), rollability, sweet residual ($p<0.01$), smoothness of surface and crumb porosity ($p<0.05$).

There were no significant differences between the replicates (Table 14) except for yeasty flavor ($p<0.05$) indicating a high reliability in the ratings by the panelists. As for the interactions, T×P was significant for salty residual ($p<0.001$), crumb porosity, bitterness, sweet residual ($p<0.01$) and yeasty odor and flavor ($p<0.05$). The P×L interaction showed significant differences for sweet flavor, sweet and salty residual ($p<0.001$), and salty flavor ($p<0.05$). P×R was significant for saltiness, sweet, salty and bitter residual ($p<0.001$), bitterness ($p<0.01$), sweetness, cohesiveness and resistance to chewing ($p<0.05$). The T×L interaction exhibited significant differences for the following 8 attributes: crust color, smoothness of surface, yeasty odor, masticatory hardness, resistance to chewing, moistness ($p<0.001$), rollability and yeasty flavor ($p<0.01$). T×R showed significant differences for bitter residual ($p<0.01$), smoothness of surface, masticatory hardness, resistance to chewing, saltiness and bitterness and salty residual ($p<0.05$). The L×R interaction was significant for crust color, smoothness of surface, masticatory hardness, resistance to chewing, moistness, and salty residual ($p<0.05$). The P×T×L interaction had significant differences for saltiness ($p<0.001$), crust color, smoothness of surface and bitter residual ($p<0.05$) while T×L×R was only significant for smoothness of surface ($p<0.001$). Given that the important interactions in this work are the P×T×L (panelist by sample) and T×L×R (sample by replicate) and the absence of significant above interactions for most descriptors/attributes is an indication of a high level of reliability in the panelists' assessment.

Breads produced with 30% substituted KCl obtained the highest ratings for smoothness of surface, yeasty odor, rollability and yeasty flavor (Table 15). They had a smoother surface when compared with the NaCl and Ag-NaCl treatments and were found to have a more pronounced yeasty odor and flavor and were more rollable than samples produced with NaCl. Breads containing Ag-NaCl were significantly different from those with NaCl for rollability only and were perceived as the saltiest when compared with the other treatments.

Figure 4 illustrates the effect of decreasing salt levels on the descriptive sensory profile of Arabic bread samples, as also summarized in Table 15. Breads with 0.6% salt were significantly darker in color than those containing 0.9% and 0.3% salt. However, looking at the means, there seems to be a decreasing trend with decreasing salt levels, except for 0.6%. Qarooni (1996) suggested that a WA above 57% led to the formation of sticky dough and the resulting breads were most likely to have a light crust color upon baking. The author also indicated that a 55% absorption is an optimal baking consistency. Furthermore, the literature suggests that bread with decreasing salt levels has a lighter colored crust. The decreased Maillard reaction during baking can be attributed to the reduced amount of free sugars because of a lower yeast activity. Less reducing sugar will be available for the reaction causing the formation of lighter colored crusts (Belz et al., 2012). Our bread samples have moisture contents ranging from 24.1% to 29.6% due to the challenge of obtaining narrow moisture level margins with the different salt levels. The analysis showed that bread samples receiving high color ratings were lower in moisture than samples with low color ratings.

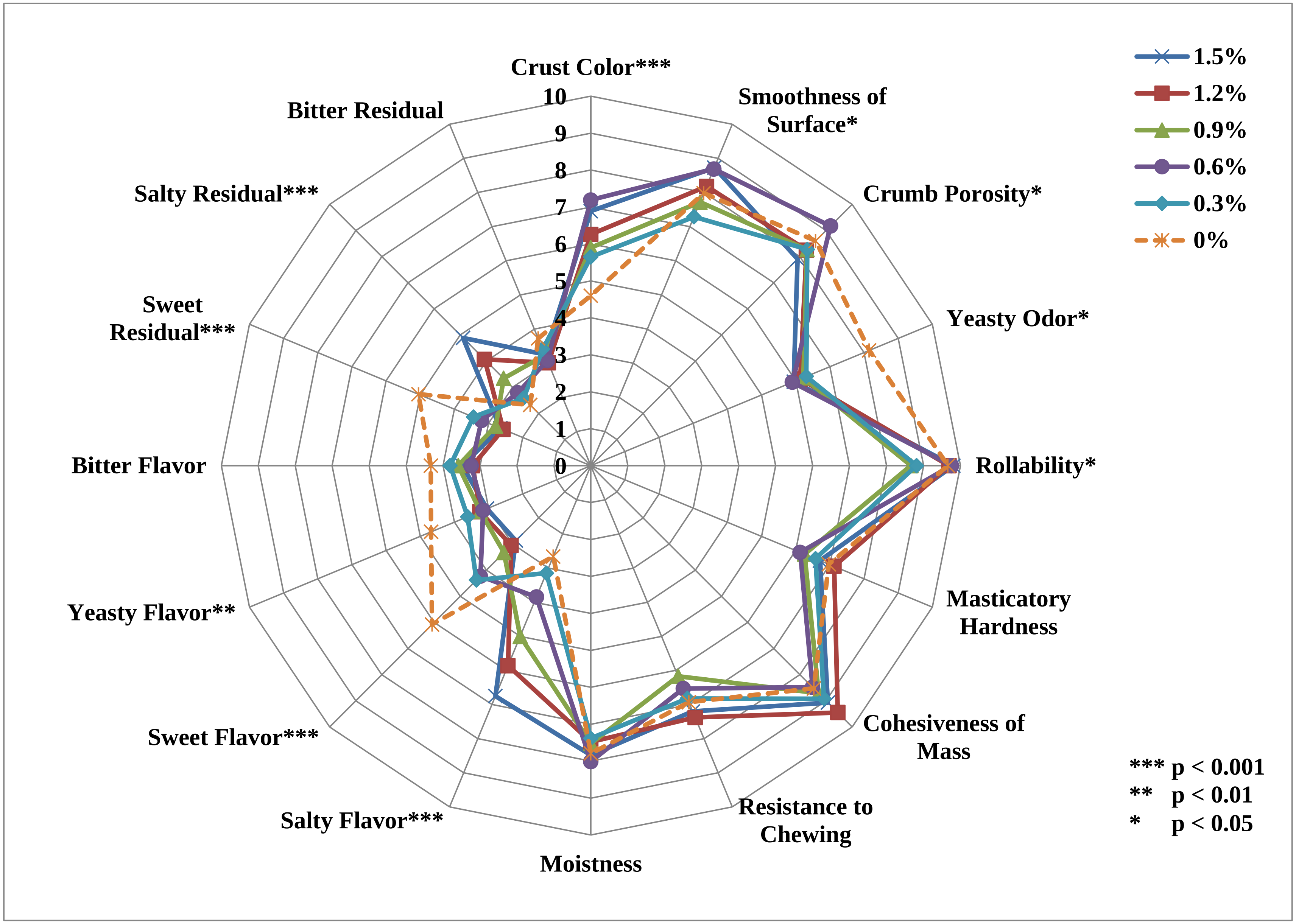


Figure 4. Sensory profile of Arabic bread samples produced with different salt levels.

As expected, bread prepared with 1.5% added salt had a significantly saltier taste and aftertaste than the rest of the samples (Table 15 and Figure 4). All levels were different from each other since decreasing salt levels reduces the perceived saltiness intensity. Both samples with 1.5% and 0.6% salt had a smoother surface than samples with 0.3% salt. Reducing the salt content yields a very sticky dough that is difficult to handle and sheet. This appearance attribute can also be affected by the incubation conditions, whereby the cabinet used was not controlled for humidity. It is important to adjust temperature and humidity in order to prevent stickiness as well as the formation of skin that might lead to bumpy surfaces after sheeting (Qarooni, 1996). Salt added at 1.5%, 1.2% and 0.6% produced bread samples that were significantly more rollable than the 0.9% level, which received the lowest score. One would expect that low salt levels should negatively impact ability of bread sample to fold and roll. However, our results showed that the sample with the lowest salt level (0.3%) was not different from the others. The percentage of salt in the formulation does not seem to have a major impact on rollability and variations might be due to baking conditions variability. Qarooni (1996) reported that the thickness of dough pieces before baking is an important quality factor. Thinner pieces (1.1 mm thickness) baked at 600°C for 21 seconds produced highly rollable bread samples. Baking thinner dough sheets at a very high temperature for a shorter time increases the bread's ability to fold and roll. The experimental samples produced in the present work were thicker than the above suggested thickness and the oven used does not reach a temperature as high as 600°C which might explain the differences observed in rollability. Moreover, the protein content of flour directly affects Arabic bread handling properties including its folding properties. As a matter of fact, Arabic bread produced with flour of intermediate protein content significantly increases pliability (Qarooni, 1996; Toufeili et al., 1999). Interestingly, none of the texture/mouthfeel attributes were significant for both type of salt and salt level, explaining the lack of major differences in the liking of texture in the acceptability test. Bread samples produced with 0.3% and 0.6% salt were significantly sweeter than all samples.

Table 16 summarizes the sensory profiles of the different Arabic bread treatments. Bread with 0.3% NaCl obtained the highest rating on yeasty flavor. The 0.6% NaCl treatment scored the highest on moistness but the lowest on masticatory hardness. The 0.9% NaCl received the highest mean for crust color and the lowest for yeasty odor and flavor. Bread with 1.2% added NaCl scored the highest on masticatory hardness while it scored the lowest on rollability and moistness. As for the NaCl-KCl treatments, bread with 0.9% salt had the highest mean for yeasty odor and the lowest for resistance to chewing. The sample with 1.5% salt scored the highest on smoothness of surface and rollability. Bread with 0.3% Ag-NaCl obtained the lowest rating on smoothness of surface. Moreover, it is interesting to point out that bread with 0.3% NaCl and 0.3% NaCl-KCl received the highest means for bitterness and sweetness respectively. According to Liem et al. (2011), there are different taste interactions that occur with sodium. Na acts as an effective bitterness inhibitor and when reducing its content in a food product, the bitter taste will be released from suppression, therefore increasing its perception.

Similarly, Na at low concentrations enhances sweetness (Liem et al., 2011) by significantly increasing the sweetness of amino acids glycine, alanine and serine (Belz et al., 2012). Furthermore, the saltiness and salty aftertaste results indicated that bread samples produced with Ag-NaCl were perceived as saltier than breads produced with either NaCl or NaCl-KCl for the same levels. However, although descriptive analysis indicates the intensity of an attribute, it does not allow to quantitatively equate and compare the salts between each other.

Comparisons with the no salt bread are summarized in Table 21 as shown in Appendix VII. Results revealed significant crust color differences with all NaCl samples except for 0.3%; with 1.2% and 1.5% NaCl-KCl samples, as well as with bread containing 0.3%, 0.6% and 1.5% Ag-NaCl. No major differences were observed on smoothness of surface except with 1.5% NaCl-KCl and 0.3% Ag-NaCl. Bread without added salt exhibited a more intense yeasty odor than all breads produced with NaCl except 0.3%, all KCl containing samples except 0.9% and all bread samples with Ag-NaCl. Our findings are in accordance with results reported by Lynch et al. (2009), where the trained descriptive panel qualified bread without salt as being more “acidic/sour” and “yeasty”. Furthermore, bread without salt was significantly sweeter (taste and residual) from all samples and less salty from all samples except for bread with 0.3% of all three types of salt. No statistically significant differences were observed between all samples and 0% salt on all texture attributes. These comparisons confirm that decreasing salt in bread drastically affects the flavor. The lack of flavor due to salt reduction was the main issue reported by Lynch et al. (2009), as no major differences in texture were observed either. Liem et al. (2011) suggested that reducing Na may negatively impact the liking of food which was not apparent in our study as omitting salt from bread did not affect consumer acceptability as much.

2. Principal Components Analysis

Figure 5 illustrates the principal components analysis for the first two components (PC). The first two and three principal components explained 51.07% and 63.82% of the variation in the sensory attributes' scores, respectively. The first principal component (PC1) accounted for 30.50% of the variation and the second principal component (PC2) accounted for 20.57%.

The first PC (displayed horizontally on Figure 5) separated attributes based on salt level. The positive side of PC1 included eight Arabic bread samples prepared with high and intermediate salt levels (1.5% and 1.2% of all three types and 0.9% NaCl and Ag-NaCl). These samples were characterized by ten attributes, namely cohesiveness of mass, resistance to chewing, masticatory hardness, crust color, saltiness and salty residual, smoothness of surface, rollability, moistness and bitter residual. The negative side of PC1 included seven bread samples of low and intermediate salt levels (0.9% NaCl-KCl, 0.6% and 0.3% of all three types of salt). These samples were characterized by eight sensory attributes, namely, moistness, crumb porosity, yeasty odor and flavor, sweetness and sweet residual, bitterness and bitter residual. It is interesting to note that moistness and bitter residual lay on the border of both sides of PC1, and although the following attributes, cohesiveness of mass, resistance to chewing, masticatory hardness and rollability belonged to the positive side of PC1, their coordinates also lay on the border of both sides, therefore characterizing all bread samples. These results clearly show the impact of salt levels on the taste and flavor characteristics of bread samples. Adding salt to bread increases the perception of saltiness (taste and aftertaste) whereas omitting salt increases the perception

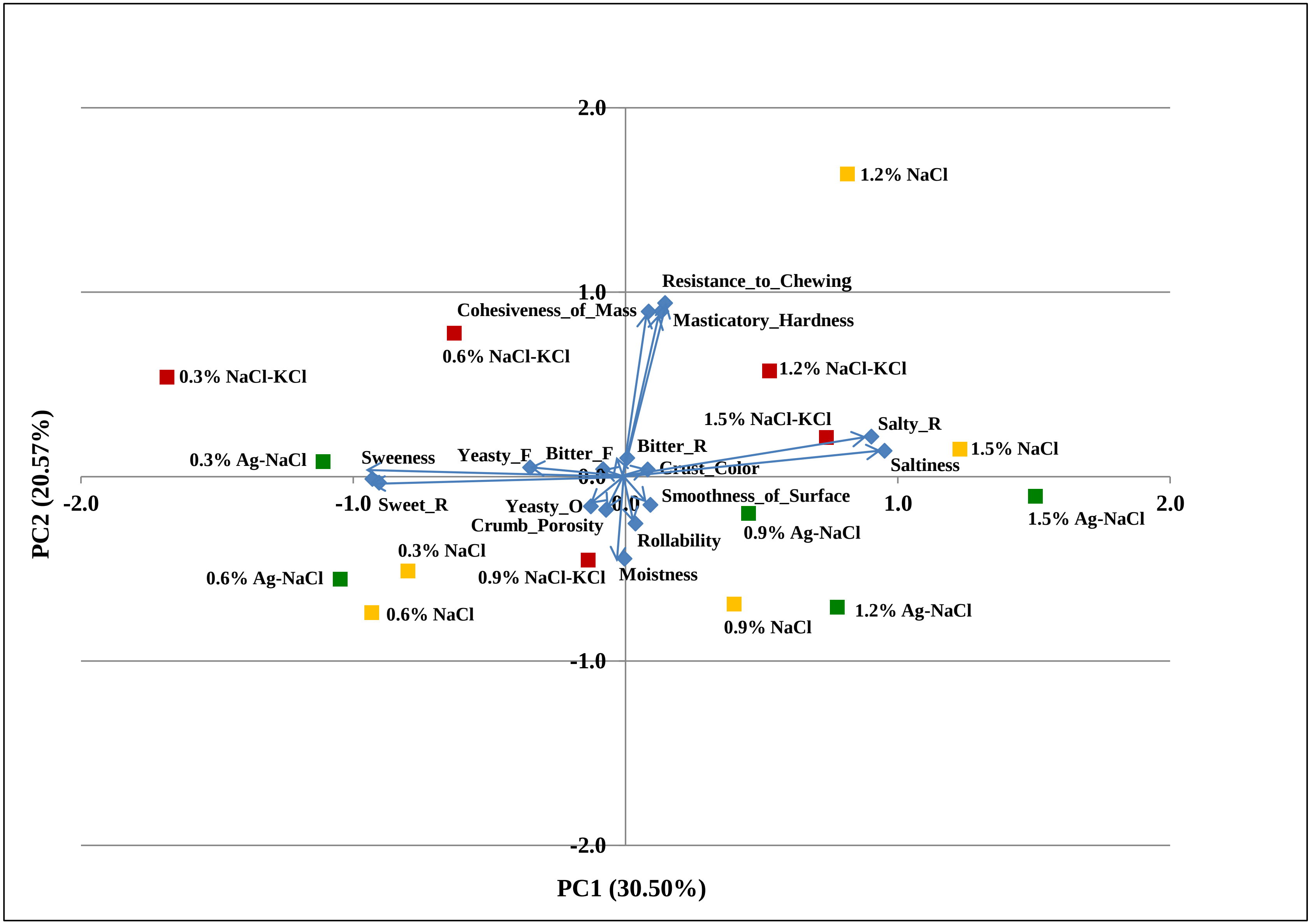


Figure 5. Principal components plot of Arabic bread samples and sensory attributes. F = Flavor; O = Odor; M = Mouthfeel; R = Residual

of yeasty odor and flavor, sweetness (taste and aftertaste), and bitterness.

The second PC (displayed vertically on Figure 5) separated sensory attributes based on type of salt. The positive side of PC2 mainly included four bread samples produced with NaCl-KCl (high and low levels). PC2 also included two samples produced with NaCl (1.5% and 1.2%) and one sample with Ag-NaCl (0.3%). They were characterized by the following eleven attributes: crust color, cohesiveness of mass, resistance to chewing, masticatory hardness, saltiness (flavor and residual), sweetness (taste and residual), yeasty flavor, bitterness (taste and residual). The negative side of PC2 mainly included four samples produced with Ag-NaCl (high and intermediate levels) and three samples produced with NaCl (intermediate and low levels). Bread produced with 0.9% NaCl-KCl also belonged to this PC. These samples were characterized by seven attributes, namely, smoothness of surface, rollability, moistness, crumb porosity, yeasty odor and sweetness (taste and residual). It is also interesting to note that the coordinates of attributes such as sweetness, yeasty, bitterness and saltiness lay on the border of both sides of PC2, indicating that type of salt characterize these attributes for all samples. This also suggests that the type of salt used does not affect the taste attributes like the level of salt does.

F. Determination of Equivalent Saltiness by Magnitude Estimation

Results of the magnitude estimation test are summarized in Tables 17 and 18 and illustrated in Figure 6.

Table 17. Antilog of the y-intercept (A), intercept on the ordinate (n), linear coefficient of determination (R^2) and power function of the results to determine the equivalent saltiness of NaCl, NaCl-KCl and Ag-NaCl relative to 0.9% NaCl in Arabic bread.

Salts	A	n	R^2	Power Function
NaCl	106.1207	0.8734	0.9897	$S = 106.1207.C^{0.8734}$
NaCl- KCl	87.3695	0.8240	0.9837	$S = 87.3695.C^{0.824}$
Ag-NaCl	133.2601	0.7842	0.9960	$S = 133.2601.C^{0.7842}$

S = Sensation perceived, C = Concentration (%)

Table 18. Equivalent concentrations of NaCl-KCl and Agglomerated NaCl relative to the different NaCl levels.

Salts	Equivalent Concentration to NaCl levels				
	0.3%	0.6%	0.9%	1.2%	1.5%
NaCl- KCl	0.35%	0.74%	1.13%	1.54%	1.95%
Ag-NaCl	0.20%	0.42%	0.67%	0.92%	1.17%

As expected, the lowest substitute concentration in Arabic bread when compared with 0.9% NaCl was observed for Ag-NaCl (0.67%) followed by NaCl-KCl (1.3%). Our results showed that both substitutes were viable in Arabic bread. Considering the curves (Figure 6) and the results displayed in Table 18, substituting NaCl with 30% KCl lowers the salting power when compared to Ag-NaCl, since a higher level of NaCl-KCl is required to provide the same saltiness intensity. These results also confirm the enhancing effect of the microcrystalline structures of Ag-NaCl in bread and support the panelists' ratings observed in descriptive analysis and in the triangle test. The lower potency of non-sodium substitutes compared with NaCl suggest that 70-80% of the salty taste percieved in food products is attributed to the Na cation explaining why its replacement by other cations

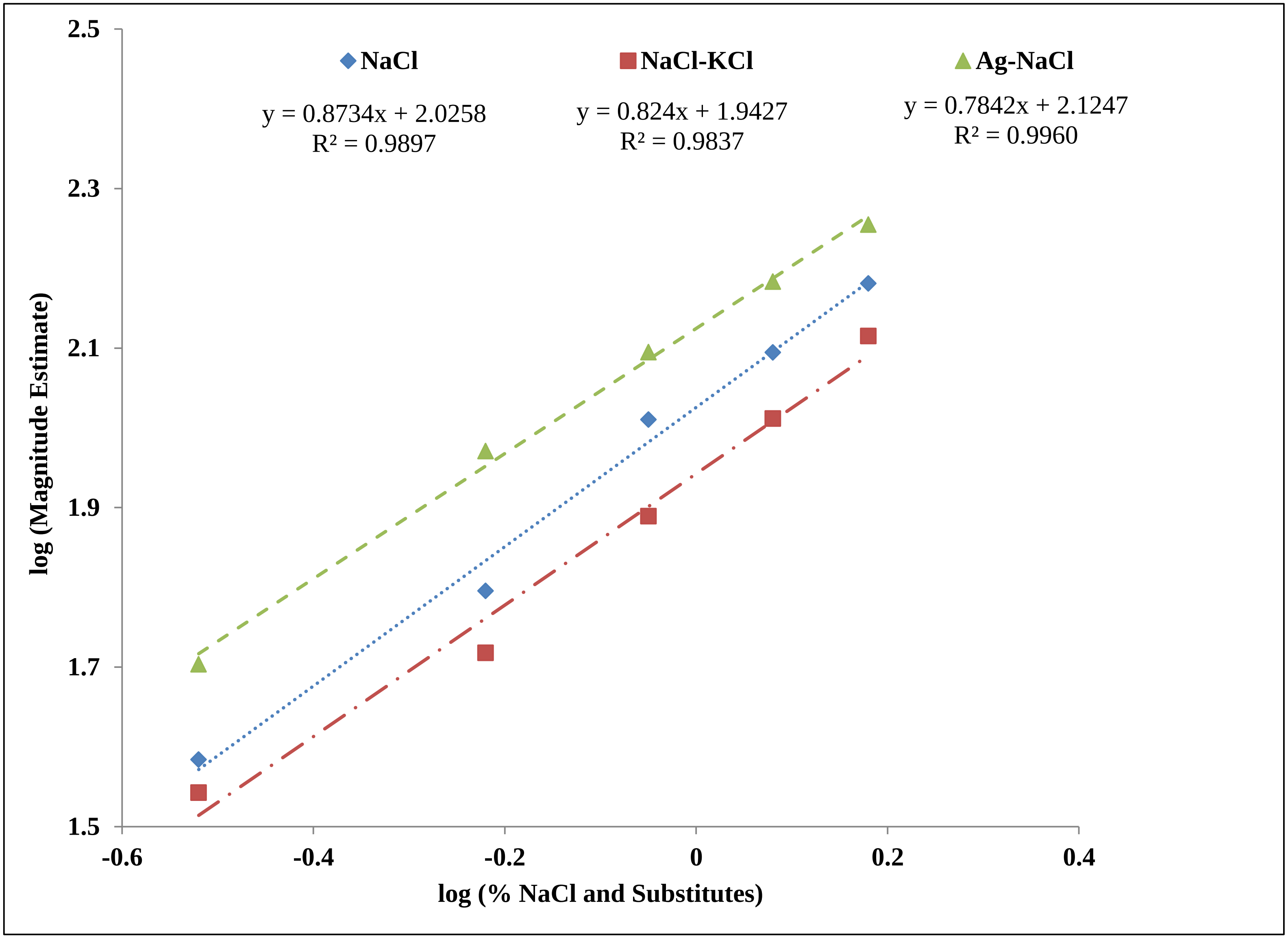


Figure 6. Results of the linear power function in Arabic bread samples produced with NaCl (blue), NaCl-KCl (red) and Ag-NaCl (green).

decreases the salty perception (Liem et al., 2011; Silva et al., 2014). Almedawar et al. (2015) reported that the average daily intake of bread in the adult Lebanese population accounts for approximately 136.8g/day. A study on bread intake in Lebanon indicated that bread provides around 1.78g salt per day (Nathalie Barakat, MSc. Thesis, AUB, June 2015). Since the optimal NaCl level in Arabic bread is 0.9% (wt/wt), bread produced with this salt level would contribute to around 1.01g of salt/day in the Lebanese diet. Bread prepared with 0.68% Ag-NaCl and 1.13% NaCl-KCl would respectively provide 0.73 and 0.9g of salt/day, therefore achieving 25.6% and 12.1% Na reduction for the same salty perception. This indicates an interesting Na reduction strategy as using Ag-NaCl as a salt substitute could not only cut down on Na but also prevent the loss of flavor that usually occurs in bread.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

A. Conclusion

The results of the study revealed that the sodium content significantly impacted the mixing properties of dough. Dough mixed with 30% KCl had a significantly lower water absorption value than dough with NaCl or Ag-NaCl, and stability was significantly higher in dough containing Ag-NaCl than dough with NaCl-KCl, indicating that KCl did not affect mixing properties. Decreasing salt levels significantly lowered stability and time to breakdown and increased mixing tolerance index of the dough. Our results showed that despite the addition of salt, the obtained doughs were relatively weak, and this is attributed to the flour of medium protein quality commonly used in Arabic bread processing. However, decreasing the salt level to 0.6% was found to be technologically feasible.

Sensory evaluation results suggested that type of salt affected consumers' acceptability for appearance, color, taste and saltiness, with NaCl and Ag-NaCl receiving the highest means, but did not affect their overall acceptability, acceptability of odor and texture of bread samples. Bread with 0.9% NaCl received the highest ratings for all acceptability attributes. It is noteworthy to mention that bread produced with 0.6% NaCl was not different from all treatments on overall acceptability, acceptability of taste and texture. Overall, no major differences were observed in the acceptability of reduced-Na Arabic bread samples (0.3 and 0.6%) when compared with the 0% salt treatment. Bread with 0.9% NaCl was found to have an optimal salty taste to the liking of participants. At levels of 0.6% and 0.9% NaCl-KCl and 0.6% Ag-NaCl, Arabic bread samples were not judged as different from the chosen control bread (0.9% NaCl) as shown in the triangle test. Descriptive analysis showed that level of salt was significant for crust color, salty taste and residual, sweet taste and residual, rollability, smoothness of surface and crumb porosity. Bread samples produced 1.5% salt were saltier (taste and aftertaste) than the rest of the samples while bread with 0.3% and 0.6% salt were significantly sweeter than all samples. Bread without salt had an intense yeasty odor and flavor, in addition to a sweet taste and aftertaste. No major differences were observed on the texture attributes between all treatments. These results revealed that reducing the salt content in bread, regardless of the type, did not affect texture as much as taste/flavor. When the equivalent saltiness of the two substitutes (NaCl-KCl and Ag-NaCl) was determined using magnitude estimation, concentrations of 0.67% and 1.13% Ag-NaCl and NaCl-KCl respectively, were found to produce the same saltiness intensity as 0.9% NaCl in Arabic bread. This indicates that a 25.6% and 12.1% Na-reduction was achieved using Ag-NaCl and NaCl-KCl respectively, without affecting the salty flavor that consumers are used to.

B. Recommendations

The results of this study indicate that reducing the salt content from 1.5% to 0.6% in bread is achievable. Although there was a perceived difference in saltiness between 0.6% and the high levels, sensory evaluation tests suggested that no major differences in texture were observed and remained acceptable to the consumers. However, other studies are needed to investigate the compensation for the effect of salt reduction on dough mixing properties for handling purposes. Na-reduced bread should also be tested for acceptability on a larger scale to better represent the Lebanese population and its characteristics should be understood in order to successfully implement a national sodium reduction strategy. Low salt bread can also have the advantage of being labeled as “low in sodium” on its packaging. This can not only result in a positive attitude by the consumer towards the claim but may also help in driving the population’s dietary Na reduction forward. In terms of saltiness, Ag-NaCl seems to be an effective salt substitute to NaCl since it has the ability to prevent the loss of flavor and cut-down on the Na content in bread at the same time. However, it has to be seen if it would be cost-efficient for bakeries and manufacturers to apply such a strategy. It is preferable not to recommend substituting NaCl with high KCl levels as potassium in large quantities may not be suitable for everyone, especially for patients suffering from heart and kidney disease.

APPENDIX I

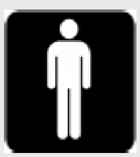
Consumer Acceptability Questionnaire

Generated by Compusense Cloud

Welcome Panelist name!

Click the ***next*** button to begin

Gender

- [ ]  Male
- [ ]  Female

Age

- [ ] 18-24
- [ ] 25-30
- [ ] 31-40
- [ ] 41-50
- [ ] >50

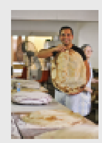
What type of bread do you mostly consume?

- ☐ 
Arabic Bread
- ☐ 
Tannour Bread
- ☐ 
Markouk Bread
- ☐ 
French Baguette
- ☐ 
Pain de Mie
- ☐ Other, kindly specify ____________

How often do you consume **ARABIC BREAD**?

- ☐ 3 times per day
- ☐ 2 times per day
- ☐ 1 time per day
- ☐ 3-4 times per week
- ☐ Once per month
- ☐ Never

What brand of Arabic bread do you usually consume?

- ☐ Wooden Bakery
- ☐ Moulin d'Or
- ☐ Pain D'Or
- ☐ 
Local bakery
- ☐ Other, kindly specify ____________

Kindly taste all bread samples in the order indicated and then answer each of the following questions.

Rinse your mouth with water **BEFORE** and **BETWEEN** samples.

Sample: BC111

All things being considered, which statement below best describes how you **FEEL** about the product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

How do you feel about the **APPEARANCE** of the product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

How do you feel about the **COLOR** of the product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

How do you feel about the **ODOR** of the product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

How do you feel about the **TASTE** of the product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

How do you feel about the **SALTINESS** of the product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

How do you feel about the **TEXTURE** of the product?

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither Like nor Dislike	Like Slightly	Like Moderately	Like Very Much	Like Extremely

Kindly indicate whether you have any additional comments on the product.

Sample: BC111

Sample: BC111

How do you feel about the **SALTINESS** of the product?

Too Little			Just-About-Right			Too Much
1	2	3	4	5	6	7

APPENDIX II

Difference Test Questionnaires

3-AFC

Panelist Number: ………
Gender: …….

Please rinse your mouth with water before starting. There are three bread samples in front of you. Two are the same and one is different. Taste each of the coded samples in the sequence presented, from **LEFT** to **RIGHT**. Within the group of three, circle the number of the **SALTIER** bread sample. Rinse your mouth with water between samples.

805 142 630

Triangle Test

Panelist number: ______

Please rinse your mouth with water before beginning. In front of you are three coded samples of Arabic bread. Two of these samples are the same and one is different. Please taste the samples in the order presented, from **LEFT** to **RIGHT**. Circle the number of the sample that is **DIFFERENT** from the other two. Rinse your mouth with water between samples.

446 606 815

APPENDIX III

Descriptive Analysis Ballot

Please rinse your mouth with water *BEFORE* starting and *BETWEEN* samples.

Please rate all samples with the line scale provided relating to the specific attribute.

Appearance

Sample: BC111

Crust Color
Color of the front layer ranging from creamy white to pale yellow.

CREAMY WHITE — PALE YELLOW

Smoothness of Surface
Absence of bumps on the surface of the front (white) layer.

BUMPY — SMOOTH

Crumb Porosity
Amount / Size of pores on the inside of the back (brownish) layer.

NOT AT ALL — VERY

Odor

Sample: BC111

Yeasty
Odor of yeast. Assessed by opening the bread sample and by smelling on the inside.

STANDARD: DOUGH

NOT AT ALL — VERY

Texture / Mouthfeel

Sample: BC111

Rollability
Ability of bread sample (both layers) to fold and roll.

CRACKS UPON ROLLING —— ROLLABLE

Masticatory Hardness
Force required to compress the sample upon biting the rolled layers of bread with incisors.

VERY SOFT —— VERY HARD

Cohesiveness of Mass
The degree to which the bread sample holds together in a mass after 3 chews.

LOOSE MASS —— COMPACT MASS

Resistance to Chewing
Number of times required to chew bread sample into small pieces.

NOT AT ALL —— VERY

Moistness
Sensation caused by the amount of water extracted from bread samples upon chewing 3 times.

NOT AT ALL —— VERY

Flavor

Sample: BC111

Saltiness
Taste elicited by table salt.

NOT AT ALL VERY

Sweetness
Taste elicited by sucrose.

NOT AT ALL VERY

Yeasty
The flavor associated with natural yeast as a leavening agent.

NOT AT ALL VERY

Bitterness
Taste elicited by caffeine.

NOT AT ALL VERY

After-Taste

Sample: BC111

Sweetness
Taste elicited by sucrose.

NOT AT ALL VERY

Saltiness
Taste elicited by table salt.

NOT AT ALL VERY

Bitterness
Taste elicited by caffeine.

NOT AT ALL VERY

APPENDIX IV

Magnitude Estimation Questionnaire

Taste the ***Reference (REF)*** sample. Assign it a **SALTINESS** rating of **100**.

Next, taste each of the bread samples in the order ***INDICATED***. Assign each sample a **SALTINESS** rating relative the **REF** sample.

REF = 100

Sample: BC111

Saltiness Rating

APPENDIX V

Statistical Models for Data

SENSORY (Acceptability)

```
UNIANOVA Overall_Feeling BY Level Type Panelist_Number
  /RANDOM=Panelist_Number
  /METHOD=SSTYPE (3)
  /POSTHOC=Level Type Type*Level (TUKEY)
  /CRITERIA=ALPHA (0.05)
  /DESIGN=Panelist_Number Type Level Panelist_Number*Type Level*Panelist_Number
 Level*Type.
```

SENSORY (Descriptive)

```
UNIANOVA Crust_Color BY Type_of_salt Level_of_salt Replicate Panelist_Number
  /RANDOM=Panelist_Number
  /METHOD=SSTYPE (3)
  /POSTHOC=Type_of_salt Level_of_salt Type_of_salt*Level_of_salt (TUKEY)
  /CRITERIA=ALPHA (0.05)
  /DESIGN=Panelist_Number Type_of_salt Level_of_salt Replicate
   Panelist_Number*Type_of_salt
   Level_of_salt*Panelist_Number Panelist_Number*Replicate Level_of_salt*Type_of_salt
   Replicate*Type_of_salt Level_of_salt*Replicate Level_of_salt*Panelist_Number*Type_of_salt
   Level_of_salt*Replicate*Type_of_salt.
```

SENSORY (PCA Descriptive)

Proc CORR;

```
proc factor data=Bread score n=30 corr outstat=stuff rotate=none method=prin min=0.001;
var     Color Crust_Color Smoothness_Surf Crumb_Porosity Yeasty_Odor Rollability
        Masticatory_Hardness Cohesiveness_of_Mass Resistance_to_Chewing Moistness
        Saltiness Sweetness Yeasty_Flavor Bitterness Sweetness_AF Saltiness_AF
        Bitterness_AF;
proc score data=Bread score=stuff out=scores;
var     Color Crust_Color Smoothness_Surf Crumb_Porosity Yeasty_Odor Rollability
        Masticatory_Hardness Cohesiveness_of_Mass Resistance_to_Chewing Moistness
        Saltiness Sweetness Yeasty_Flavor Bitterness Sweetness_AF Saltiness_AF
        Bitterness_AF;
proc print data=scores;
proc plot;
```

```
plot factor2*factor1=sample factor3*factor1=sample;
run;
```

FARINOGRAPH

```
UNIANOVA Water_Absorption BY Type Level Replicate
  /METHOD=SSTYPE (3)
  /INTERCEPT=EXCLUDE
  /POSTHOC=Type Level (TUKEY)
  /CRITERIA=ALPHA (0.05)
  /DESIGN=Type Level Replicate Level*Type Replicate*Type Level*Replicate.
```

APPENDIX VI

Farinograph Supplementary Table

Table 19. Means of farinograph variables and significant levels for comparisons (Dunnett) with 0% salt.

Variable	Type of Salt															
	0% salt	NaCl					NaCl + KCl					Ag-NaCl				
		0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%
WA	58.7	58.0	57.5^{*}	57.4^{**}	57.3^{**}	57.0^{**}	57.7^{*}	57.3^{**}	56.5^{***}	56.6^{***}	56.6^{***}	58.5	57.7^{*}	57.6^{*}	57.3^{**}	56.7^{***}
DDT	1.9	1.8	1.7	1.8	1.7	2.0	2.1	1.7	1.7	2.1	2.1	1.7	1.9	1.9	2.1	2.2
Stability	3.5	3.5	5.1	5.8^{*}	7.0^{***}	8.1^{***}	3.4	4.0	4.1	6.6^{**}	7.7^{***}	3.2	4.2	6.8^{***}	8.2^{***}	8.7^{***}
TTB	3.1	3.3	3.1	3.5	3.5	3.0	2.9	3.0	3.4	3.5	3.3	2.6	3.1	3.1	3.7	3.9
MTI	60.5	59.5	60.5	65.5	60.0	58.0	63.5	66.0	65.0	61.5	70.5	79.0^{*}	72.0	62.0	56.5	43.0^{*}

*$p<0.05$; **$p<0.01$; ***$p<0.001$

WA = Water Absorption; DDT = Dough Development Time; TTB = Time to Breakdown; MTI = Mixing Tolerance Index

APPENDIX VII

Sensory Supplementary Tables

Table 20. Means of acceptability variables and significant levels for comparisons (Dunnett) with 0% salt.

Variable	Type of Salt															
	0% salt	NaCl					NaCl + KCl					Ag-NaCl				
		0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%
Overall	5.31	5.86	5.83	6.26**	5.82	5.94	5.03	5.01	6.36***	5.88	5.89	5.40	5.96	5.97	6.21**	5.63
Appearance	5.36	5.90	6.10	6.71***	6.01	6.17*	5.32	5.43	6.51***	6.19*	5.79	5.68	6.25**	6.06	6.44***	5.94
Color	5.75	6.06	6.28	6.68**	5.93	6.43	5.36	5.67	6.50*	6.08	6.01	5.83	6.28	6.21	6.54*	6.18
Odor	6.18	6.17	6.50	6.64	5.81	6.01	5.76	5.71	6.50	6.28	6.47	6.00	6.15	6.44	6.54	6.19
Taste	5.15	5.78	6.07*	6.07*	5.65	5.86	4.60	5.04	5.83	5.88	5.72	5.00	5.74	5.96	6.24**	5.86
Saltiness	4.86	5.33	5.67*	5.94**	5.47	5.62	4.44	4.85	5.60	5.61	5.78*	4.69	4.85	5.46*	6.13***	5.86**
Texture	4.69	5.65	5.57	6.11***	5.60*	5.64*	4.68	4.93	5.97***	5.93***	5.51	4.72	6.04***	5.93***	6.01***	5.50

*p<0.05; **p<0.01; ***p<0.001

Table 21. Least squares means of acceptability variables and significant levels for comparisons (Dunnett) with 0% salt

Variable	Type of Salt														
		NaCl					NaCl + KCl					Agglomerated NaCl			
	0%	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%	0.3%	0.6%	0.9%	1.2%	1.5%
Crust Color	4.58	3.57	8.00***	8.11***	7.41**	7.33**	6.07	5.84	4.66	6.75*	6.27*	7.32**	7.71***	4.93	4.62	7.0**
Smoothness of surface	7.98	7.43	7.41	6.44	7.51	8.28	8.80	9.15	7.80	8.41	10.29*	5.65**	9.50	8.93	8.63	7.62
Crumb Porosity	8.55	8.58	8.35	8.72	8.44	7.33	8.53	8.16	10.18	8.13	8.59	7.73	8.30	8.62	8.18	7.82
Yeasty Odor	8.15	7.18	6.01*	4.68***	5.40***	5.95*	6.07*	6.15*	7.77	6.33*	6.44*	5.68*	5.64*	6.20*	6.66	5.44**
Rollability	9.66	8.03	9.96	8.14	7.70*	8.92	9.23	9.31	9.05	10.49	11.13	9.17	10.02	8.78	10.88	9.37
Masticatory Hardness	6.97	5.94	5.20	6.62	9.15	7.00	6.77	7.44	5.60	6.68	6.34	7.02	5.75	6.57	5.51	6.80
Cohesiveness of Mass	8.53	8.56	8.18	8.26	10.04	9.02	9.47	9.23	8.97	9.59	8.98	8.75	8.01	8.90	8.71	9.21
Resistance to Chewing	6.93	6.01	5.80	6.43	9.07	7.56	7.08	7.77	5.42	7.21	6.81	7.36	6.03	6.66	5.85	7.22
Moistness	7.79	8.35	8.63	6.97	6.33	7.80	6.81	7.21	3.39	8.13	8.50	6.98	8.19	7.20	7.98	7.23
Salty Flavor	2.66	3.23	3.67*	4.97***	6.08***	6.76***	2.98	4.02**	4.38***	5.54***	6.07***	3.23	3.85*	5.64***	5.97***	7.41***
Sweet Flavor	6.08	4.15***	4.24***	3.05***	2.90***	2.72***	4.73**	3.75***	3.81***	3.21***	3.30***	4.25***	4.70**	3.12***	3.05***	2.60***
Yeasty Flavor	4.68	4.15	2.98**	2.51***	2.65***	2.81**	3.31	3.34*	4.06	3.28*	3.54	3.38	3.15*	3.13*	3.82	2.78**
Bitter Flavor	4.33	4.30	3.37	4.00	3.15	3.32	3.51	3.32	3.56	3.52	3.50	3.62	3.03	3.41	2.95	3.63
Sweet Residual	5.05	3.34***	3.28***	2.51***	2.46***	2.55***	3.70***	3.00***	3.15***	2.53***	2.74***	3.29***	3.31***	2.71***	2.72***	2.66***
Salty Residual	2.32	2.58	2.80	3.37**	4.58***	4.85***	2.56	2.81	3.23**	3.89***	4.54***	2.61	2.77	3.43***	3.73***	5.27***
Bitter Residual	3.73	3.33	2.91	3.25	3.02	3.00	3.21	3.37	3.08	2.96	3.23	3.70	2.95	3.40	3.06	3.56

APPENDIX VIII

Sensory Profile of Arabic Bread Samples

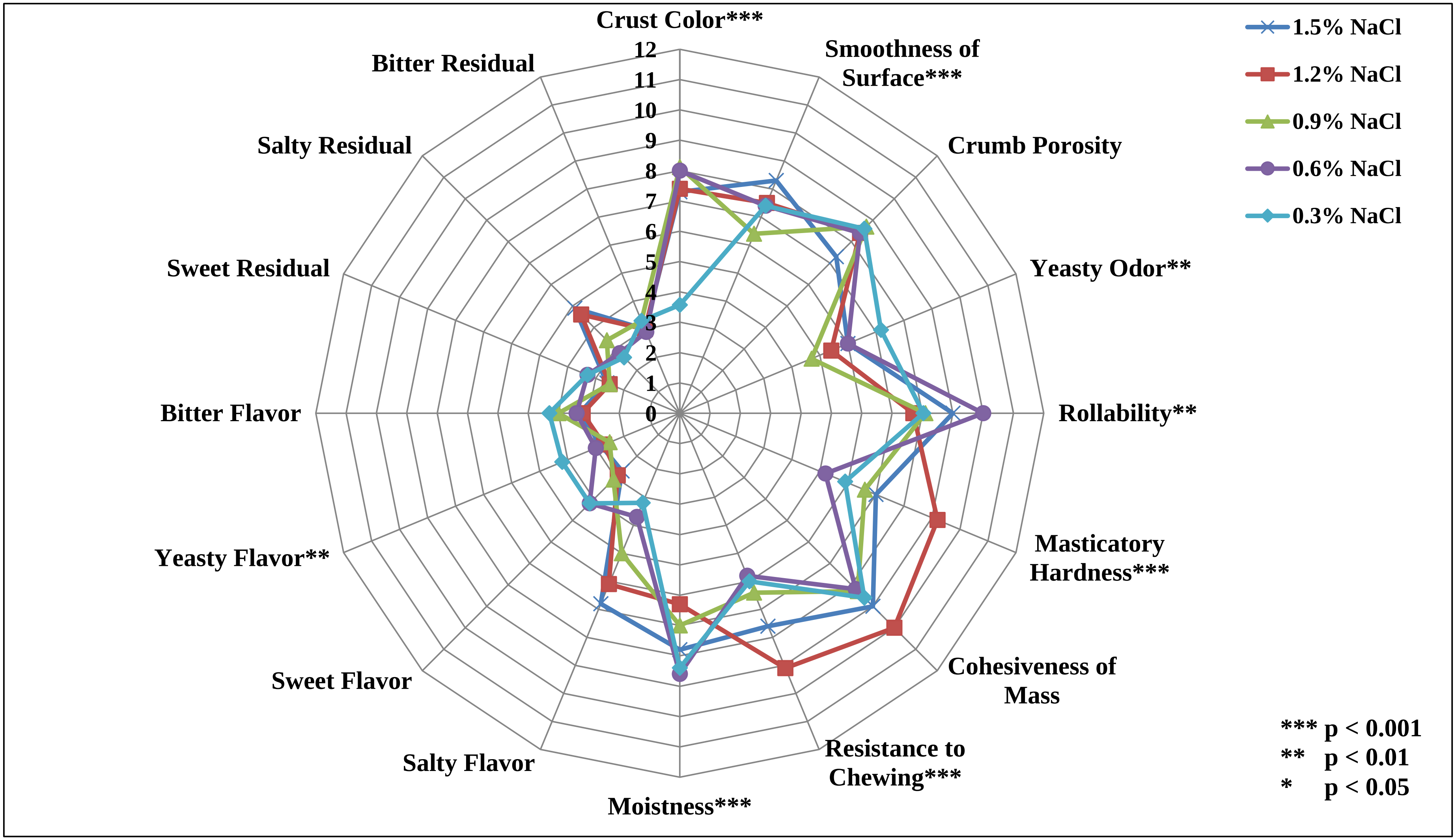


Figure 7. Sensory profile of Arabic bread samples produced with different NaCl levels.

Figure 8. Sensory profile of Arabic bread samples produced with different NaCl-KCl levels.

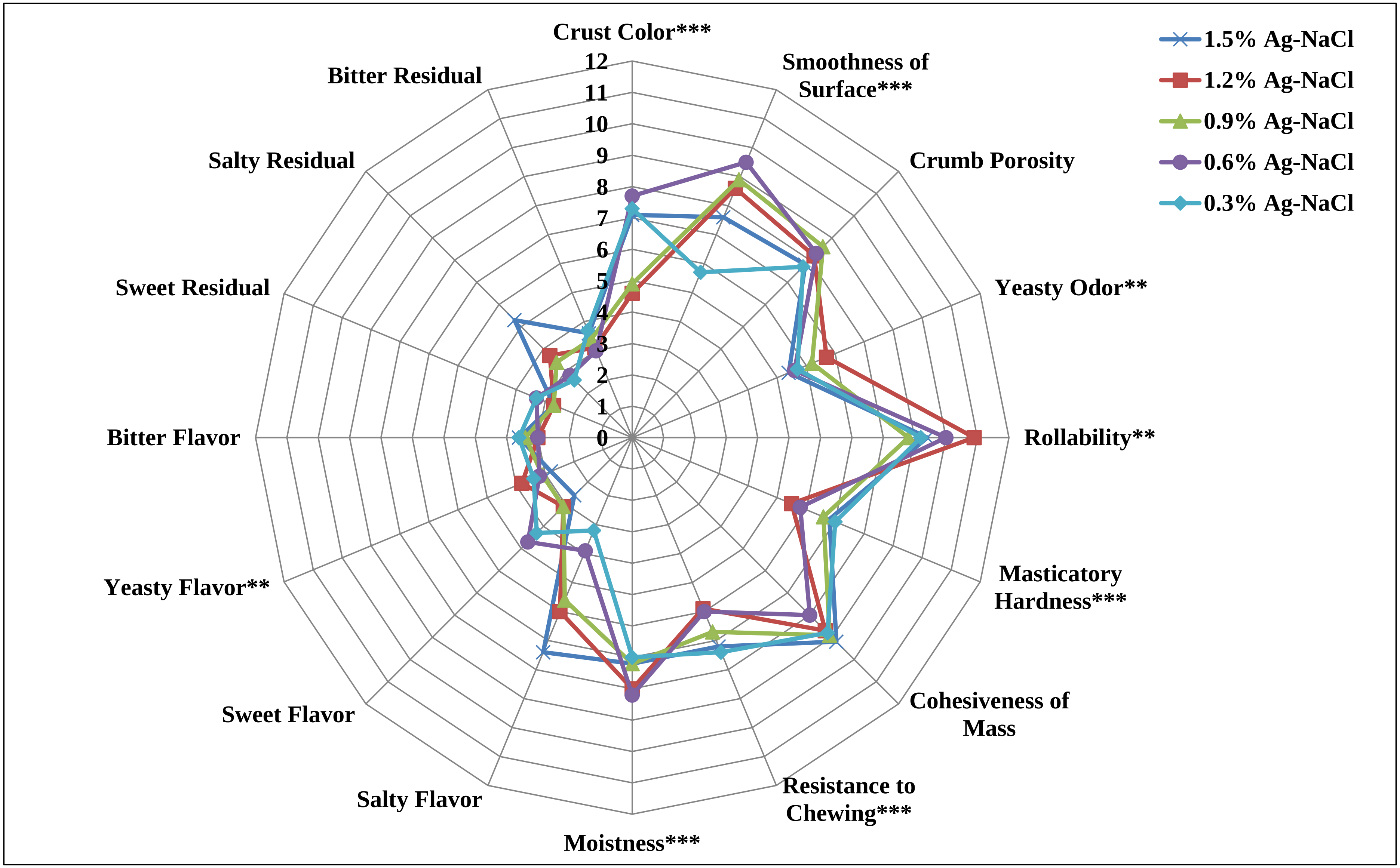


Figure 9. Sensory profile of Arabic bread samples produced with different Ag-NaCl levels.

APPENDIX IX

Chemical Reagents

Reagent	*Preparation*
50% HCl	Mix 50 ml concentrated HCl with 50 ml deionized water
0.5% Cs, 0.5*N* HCl Cesium stock solution	Dissolve 6.334g CsCl in 500 ml deionized water. Add 41 ml concentrated HCl. Make up to volume in a 1 liter volumetric flask.
Sodium standard solution	Pipet 1 ml Na stock solution (1000 ppm Na) in 100 ml volumetric flask. Dilute to volume with deionized water. pipet 0, 4, 8, 12, 16, 20 and 24 ml from the 10 ppm Na solution in separate 100 ml volumetric flasks. Add to each flask 20 ml Cs stock solution.
Potassium standard solution	Pipet 2 ml K stock solution (1000 ppm K) in 100 ml volumetric flask. Dilute to volume with deionized water. pipet 0, 4, 8, 12, 16, 20 and 24 ml from the 10 ppm K solution in separate 100 ml volumetric flasks. Add to each flask 20 ml Cs stock solution. Make up to volume with deionized water.

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