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REDUCTION OF SODIUM CONTENT IN BAKING THROUGH NEW TECHNOLOGICAL APPROACHES

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Abstract. Excessive sodium consumption is a global public health concern, negatively impacting life expectancy and overall quality of life. Bread, one of the world's staple foods, contributes significantly to total sodium consumption, making it imperative to reformulate traditional recipes to reduce salt content while maintaining product acceptability. An effective strategy involves gradually reducing the amount of salt, allowing consumers to adapt to a less intense taste. Another approach involves the use of potassium chloride, which can partially replace sodium in the composition of bakery products, but requires adjustments to eliminate the slightly bitter taste. In this process, yeast plays an essential role, as natural fermentation contributes to the development of a more complex flavor profile, amplifying the perception of salty taste and reducing the need for added salt. Another key factor in reducing sodium is the use of flavor enhancers, such as yeast extracts, glutamates and hydrolyzed protein nucleotides, which enhance the perception of saltiness without increasing sodium content. These ingredients can be combined with salt substitutes, thus helping to maintain an optimal taste balance. Implementing these solutions requires an integrated technological approach, which includes product reformulation, nutritional education and public policies aimed at supporting the reduction of sodium in the diet.

Keywords: *bread, consumer health, sodium chloride, technological processes, sourdough.*

Rezumat. Consumul excesiv de sodiu reprezintă o preocupare globală în domeniul sănătății publice, având un impact negativ asupra speranței de viață și calității generale a vieții. Pâinea, unul dintre alimentele de bază la nivel mondial, contribuie semnificativ la consumul total de sodiu, ceea ce face imperativă reformularea rețetelor tradiționale pentru a diminua conținutul de sare, păstrând în același timp acceptabilitatea produsului. O strategie eficientă presupune reducerea treptată a cantității de sare, permițând consumatorilor să se adapteze la un gust mai puțin intens. O altă abordare implică utilizarea clorurii de potasiu, care poate înlocui parțial sodiul în compoziția produselor de panificație, având însă nevoie de ajustări pentru a elimina gustul ușor amar. În acest proces, maiaua joacă un rol esențial, deoarece fermentația naturală contribuie la dezvoltarea unui profil aromatic mai complex, amplificând percepția gustului sărat și reducând nevoia de adaos de sare. Un alt factor-cheie în reducerea sodiului este utilizarea potențiatorilor de aromă, precum extractele de drojdie, glutamații și nucleotidele proteice hidrolizate, care intensifică percepția săratului fără a crește conținutul de sodiu. Aceste ingrediente pot fi combinate cu substituenți de sare, contribuind astfel la menținerea unui echilibru gustativ optim. Implementarea acestor soluții necesită o abordare tehnologică integrată, care să includă reformularea produselor, educația nutrițională și politici publice menite să sprijine reducerea sodiului în alimentație.

Cuvinte-cheie: *pâine, sănătatea consumatorului, clorură de sodiu, procese tehnologice, maia.*

1. Introduction

Bread has been a fundamental part of the human diet for thousands of years, serving as a primary source of energy and essential nutrients. It provides carbohydrates for energy, proteins for muscle growth and repair, fiber for digestive health, and an array of vitamins and minerals vital for metabolism [1]. However, beyond its nutritional benefits, bread is also a significant contributor to dietary sodium intake, which has raised concerns regarding its impact on public health.

Excessive sodium consumption is a pressing global health issue, as it is closely linked to serious conditions such as hypertension, cardiovascular diseases, stroke, and kidney disorders [2]. The World Health Organization (WHO) recommends a maximum sodium intake of 2 g/day, yet global consumption rates often exceed 4.31 g/day, significantly surpassing the recommended levels [3]. Recognizing the urgent need to address this issue, the WHO introduced an ambitious goal in 2013 to reduce global sodium intake by 30% by 2025. However, due to slow progress, the deadline was extended to 2030 [4].

Among processed foods, bread is one of the most significant sources of dietary sodium, accounting for up to 34% of total daily intake in certain populations, particularly in regions where bread consumption is high [5]. The high sodium content in bread is largely due to the amount of salt added during the baking process, which not only enhances flavor but also plays a crucial role in gluten structure development and yeast activity.

In many developed countries, bread consumption has been steadily declining, yet in Romania and Moldova, it remains exceptionally high. Statistics indicate that Romanians consume an average of 7.6 kg of bread/month, while in Moldova, the figure rises to 10 kg/month, both exceeding the European Union (EU) average [6]. Given these high consumption rates, it is imperative to implement effective strategies to reduce sodium intake from bakery products in these countries.

Sodium reduction in bread is not just a health recommendation; it is becoming a regulatory priority across the globe. Countries are adopting various initiatives to lower sodium intake through food reformulation, consumer awareness campaigns, and strengthened regulations. The WHO assesses national sodium reduction efforts using a reference scale, where Romania and Moldova currently hold scores of 3 and 2, respectively. To reach level 4, additional measures must be implemented [7].

Reducing sodium in bread presents several challenges. Salt not only contributes to the taste and texture of bread but also affects dough elasticity and fermentation processes [8]. Despite these challenges, food manufacturers are under increasing pressure to find innovative solutions that maintain product quality while significantly reducing sodium content.

There are several scientifically backed strategies to reduce sodium in bread without compromising its quality or consumer acceptance:

- **Recipe reformulation.** Adjusting bread formulations by gradually reducing added salt levels, allowing consumers to adapt to lower sodium content over time.
- **Alternative ingredients.** Replacing regular salt with low-sodium sea salts, potassium chloride, yeast extracts, and natural flavor enhancers to maintain taste while reducing sodium.
- **Use of enzymes and functional ingredients.** Enzymes and certain proteins can improve bread texture and structure, compensating for the functional roles of salt in dough processing.
- **Sourdough fermentation.** Utilizing sourdough fermentation as a natural flavor enhancer can help compensate for reduced salt while also improving the bread's nutritional profile.
- **Advanced processing technologies.** Innovative baking methods and processing techniques can be optimized to produce lower-sodium bread while maintaining the sensory qualities expected by consumers.
- **Consumer education and label transparency.** Clear labeling of sodium content on packaging and public awareness campaigns can encourage consumers to make healthier choices.
- **Government regulations and initiatives.** Implementing and enforcing sodium reduction policies, including industry-wide targets, procurement policies for public institutions, and mandatory front-of-pack labeling.

Reducing sodium levels in bread is a crucial step toward improving public health and aligns with international recommendations for healthier dietary patterns. The bakery industry has a responsibility to adopt effective sodium reduction strategies that meet both consumer expectations and regulatory standards. By reformulating recipes, leveraging alternative ingredients, refining processing techniques, and enhancing consumer awareness, the industry can successfully contribute to global sodium reduction efforts.

In countries like Romania and Moldova, where bread consumption remains high, implementing these strategies is particularly important. Collaborative efforts between government agencies, food manufacturers, and consumers will be essential to achieving sustainable reductions in sodium intake, ultimately leading to improved health outcomes and a lower burden of sodium-related diseases.

As consumer preferences continue to shift towards healthier and more transparent food options, the demand for low-sodium bread alternatives will grow. The adoption of these strategies not only benefits public health but also provides the bakery industry with an opportunity to innovate and align with emerging health-conscious market trends.

2. The physiological importance of sodium chloride and legal regulations

Salt, scientifically known as sodium chloride (NaCl), is a crystalline compound composed of sodium (Na) and chlorine (Cl) ions in a 1:1 ratio. It is an ionic compound, meaning it forms through the electrostatic attraction between positively charged sodium ions and negatively charged chloride ions. This structure gives salt its characteristic crystalline appearance and stability [9].

Salt is one of the most abundant minerals on Earth, found naturally in seawater, rock salt deposits, and saline lakes. It plays a vital role in human and animal physiology, contributing to fluid balance, nerve transmission, and muscle function. In its edible form, table salt is widely used as a seasoning and preservative in the food industry [10]. Additionally, sodium chloride has numerous industrial applications, including the production of chemicals like sodium hydroxide and chlorine, as well as its use in de-icing roads and water treatment [11].

Among the significant sodium salts occurring naturally, key examples include sodium chloride, sodium carbonate, sodium borate, sodium nitrate, and sodium sulfate. These compounds are notable for their widespread presence in various environments and their diverse applications [12].

Regarding legal regulations, sodium chloride is subject to various guidelines depending on its use. For example, in the European Union, it has been approved as a basic substance under Regulation (EU) 2017/1529 for specific applications, such as a fungicide in agriculture. These regulations ensure its safe and effective use in different industries [13].

2.1. The effects of salt consumption on human health

The effect of salt on human health has been studied and analyzed in several scientific articles. Sodium chloride is essential for sustaining life as it underpins core physiological processes. Sodium and chloride are crucial for preserving membrane potential, which allows for nerve impulse transmission, muscle contractions, and cardiac activity. In addition, sodium absorption in the small intestine facilitates the uptake of nutrients, including amino acids, glucose, and water [14].

Excessive sodium consumption is closely linked to high blood pressure, a significant risk factor for cardiovascular diseases such as heart attacks and strokes. Scientific research highlights that reducing sodium intake lowers blood pressure, improves vascular health, and decreases mortality rates from hypertension-related conditions. Sodium impacts fluid balance, nerve function, and muscle contraction, but excessive amounts lead to harmful changes in arterial structure and increased systemic resistance. To mitigate these risks, global health recommendations advocate limiting daily sodium intake to less than 5 grams, alongside public health strategies like reducing sodium in processed foods and raising consumer awareness. Balancing sodium intake is essential for promoting overall health and preventing cardiovascular disease [15,16].

In an adult weighing around 70 kg, the body contains approximately 92 g of sodium. Despite individual variations in distribution across body compartments such as extracellular and intracellular fluids, the concentration of sodium remains consistent among all people, regardless of age, gender, or physical activity. Sodium is vital for maintaining fluid balance, nerve function, and muscle activity [17].

Excessive sodium intake negatively impacts cardiovascular health, bone metabolism, and immune function. While the body only requires 180−230 mg of sodium daily for essential physiological processes, modern diets often exceed this amount, increasing risks of hypertension, bone loss, and inflammatory imbalances. Reducing salt consumption and incorporating more potassium-rich foods can help support long-term health and balance [18,19].

Within recommended intake levels, sodium plays a crucial role in maintaining physiological balance. It supports plasma volume regulation, stabilizes cell membrane potential, facilitates neural transmission, enables muscle contractions, and ensures optimal kidney function. Additionally, sodium is essential for transporting key nutrients like glucose and amino acids across cell membranes, contributing to overall metabolic efficiency [20].

The key roles of sodium in the human body:

- **Fluid balance.** Regulates water distribution between cells and extracellular spaces.
- **Electrochemical gradient.** Maintains the gradient across cell membranes, vital for cellular function.
- **Nerve impulse transmission.** Facilitates communication between nerve cells.
- **Muscle contraction.** Enables contraction of muscles, including the heart.
- **Nutrient absorption.** Assists in absorbing glucose, amino acids, and water in the small intestine.
- **Acid-base balance.** Helps neutralize acids and maintain pH equilibrium.
- **Intercellular communication.** Supports signaling and metabolic processes between cells [21].

Sodium plays a crucial role in maintaining balance in the body, with absorption and regulation tightly controlled by neurohormonal mechanisms, primarily through the kidneys, which manage excretion and retention based on dietary intake. Approximately 95% of the body's sodium is stored in extracellular fluid, with significant amounts in the bones, skin, and muscles [22].

Excessive salt intake is a major global health concern, contributing to around 5 million deaths annually. It is strongly linked to hypertension, a key risk factor for cardiovascular diseases, the leading cause of mortality worldwide. Beyond blood pressure regulation, excessive sodium affects kidney function, brain health, vascular integrity, and immune response, promoting inflammation and disease susceptibility. Reducing salt consumption and balancing sodium with potassium intake can help mitigate these risks and support long-term health [23].

Sodium chlorine also has negative effects on health, including the following:

- **Increases blood pressure**. Contributes to hypertension, raising the risk of cardiovascular diseases.
- **Impacts kidney function**. Overloads the kidneys, potentially leading to chronic kidney disease.
- **Causes fluid retention**. Results in swelling and bloating due to excess water retention.
- **Weaken bones**. Accelerates calcium loss, increasing the likelihood of osteoporosis.
- **Damages blood vessels**. Leads to vascular stiffness and reduced flexibility.
- **Promotes atherosclerosis**. Contributes to arterial plaque buildup and narrowed blood vessels [24].

2.2. Legislative regulations regarding the recommended daily intake of sodium

Sodium consumption guidelines vary across nations, though many follow recommendations from global health organizations. The WHO advises individuals to keep daily sodium intake below 2 g to reduce the risk of chronic illnesses.

In the EU, food manufacturers must label salt content in packaged items based on their sodium levels. Some countries enforce stricter regulations Belgium, for example, sets a maximum of 2% salt on dry matter for bread, while Portugal and Croatia impose an upper limit of 1.4 g/100 g of bread [25,26].

Across Europe, regulating sodium levels in food, especially in bakery products has become a key focus of health initiatives. Excessive salt intake is linked to various health risks, prompting the EU to implement measures ensuring safer food consumption.

Several regulations oversee food additives and sodium content. Regulation (EU) No. 1129/2011 provides a comprehensive list of approved additives, while Regulation (EU) 2022/650 refines specifications for sodium-based compounds used in food production. These policies aim to create uniform standards across member states, ensuring transparency and consumer protection [27].

Beyond legislation, industry organizations play a role in shaping the market. The Federation of European Manufacturers and Suppliers of Ingredients for the Bakery, Confectionery and Pastry Industries representing bakery ingredient suppliers, has set strategic goals for 2024–2029, promoting innovation and sustainability within the sector. These efforts align with broader EU objectives to reduce sodium consumption while maintaining food quality [28].

Beyond Europe, Argentina has established sodium restrictions for processed foods, including bread, meat products, soups, and seasoning mixes, with penalties for exceeding permissible limits. Additionally, several European nations have introduced policies to regulate school meals, aiming to lower sodium intake among children [29].

Many countries have implemented sodium regulations in bakery products through mandatory limits, voluntary targets, and industry collaborations. Across the EU, nearly half of the member states adopted legal measures like salt taxes, mandatory nutrition labeling, and regulated health claims to encourage sodium reduction in processed foods, including bakery items [30].

Belgium has focused on agreements between the bakery sector and the Ministry of Health to promote iodized salt use, while also considering salt taxes and mandatory labeling for high-sodium products to further strengthen reduction efforts [31].

In line with WHO recommendations, Moldova aims to limit daily sodium intake to under 2 g (5 g of salt). Through its National Program (2014–2020), the country set a goal of reducing salt consumption by 30%, supported by educational campaigns focused on raising awareness and fostering collaboration with the food industry. These regulatory approaches highlight a global shift toward stricter sodium control, balancing public health initiatives with industry adaptation [32].

In both Moldova and Romania, efforts are being made to regulate the sodium content in bakery products, as excessive salt consumption is a recognized health risk. In Moldova, studies have shown that adults consume an average of 10.8 g of salt/day, significantly exceeding the recommendations set by the WHO. Given that bread and baked goods are primary sources of sodium, authorities have launched awareness campaigns to encourage a reduction in salt intake and promote healthier choices [33].

Moldova has implemented measures to regulate sodium levels in bakery products, recognizing the health risks associated with excessive salt consumption. In 2022, the government set gradual targets for reducing salt content in bread, initially limiting it to 1.5 g/100 g of product, with a further reduction to 1 g planned for 2024. These regulations are part of the National Program for the Prevention and Control of Noncommunicable Diseases (2023–2027), aiming to lower sodium intake and improve public health [34].

Bread and other baked goods are among the most common sources of salt in the daily diet of Moldovan consumers. To address this concern, authorities have introduced several initiatives to encourage lower sodium consumption.

The regulation promotes:

- Monitoring and regulating sodium levels in bakery products to prevent excessive intake.
- Encouraging reformulation in the food industry by working with manufacturers to adjust recipes for lower salt content.
- Educating consumers through public awareness campaigns about the health risks associated with high sodium intake.

These measures are in line with broader European strategies aimed at improving food standards and ensuring healthier consumption habits. By setting clear guidelines for sodium reduction in bakery products, Moldova is actively contributing to efforts that support long-term well-being and disease prevention [32-34].

Similarly, Romania has established food safety and labeling regulations for bakery products to ensure compliance with European standards. The National Authority for Consumer Protection collaborates with industry representatives to enhance adherence to regulations, focusing on proper ingredient disclosure and the responsible use of additives [35].

In Romania, reducing sodium levels in bakery products has become an essential focus of national health strategies. Given that bread and baked goods are among the leading sources of salt in the average Romanian diet, authorities have introduced measures to minimize excessive sodium consumption and encourage healthier food choices. One significant regulation applies to food products sold in schools and preschools, limiting the salt content to a maximum of 1.5 g/100 g of product. This policy is designed to foster better dietary habits among children and reduce their long-term risk of developing health conditions linked to high sodium intake.

To further support sodium reduction, manufacturers are increasingly exploring alternatives to traditional salt. Reformulating recipes, incorporating natural flavor enhancers, and utilizing low-sodium substitutes are among the strategies aimed at maintaining the quality and taste of bakery products while reducing overall sodium content. These efforts align with broader European food policies, which emphasize healthier consumption and improved nutritional standards.

2.3. The level of sodium chloride in bakery products and the frequency of their consumption

Across Europe, various food products contribute to daily sodium intake (Figure 1), with baked goods leading the list. Items such as bread, biscuits, cakes, breakfast cereals, pastries, noodles, and cereal bars all contain added sodium, whether from salt itself or other ingredients like baking powder and leavening agents [36].

Bread, in particular, plays a substantial role in dietary salt consumption. Studies indicate that eating 150 g of bread made with 20 g of salt/kg of flour can account for roughly one-quarter of a person's average daily salt intake, about 10 g/day. Among European nations, bread consumption varies widely. Turkey reports the highest annual per capita consumption at 104 kg, followed by Bulgaria at 95 kg, while the UK has the lowest at just 32 kg. Overall, Europeans consume an average of 59 kg of bread/year. Some countries, including the Netherlands, Belgium, the UK, and Poland, have seen a gradual decline in bread consumption. In Poland, for example, the daily intake was recorded at 145 g in 2015, meaning that eating wheat baguettes alone could provide as much as 4.4 g of salt daily - covering 87% of the maximum recommended intake defined by the WHO. Other bread types supply between 1.6 and 2.2 g of salt, amounting to 32-44% of the recommended limit [4,37].

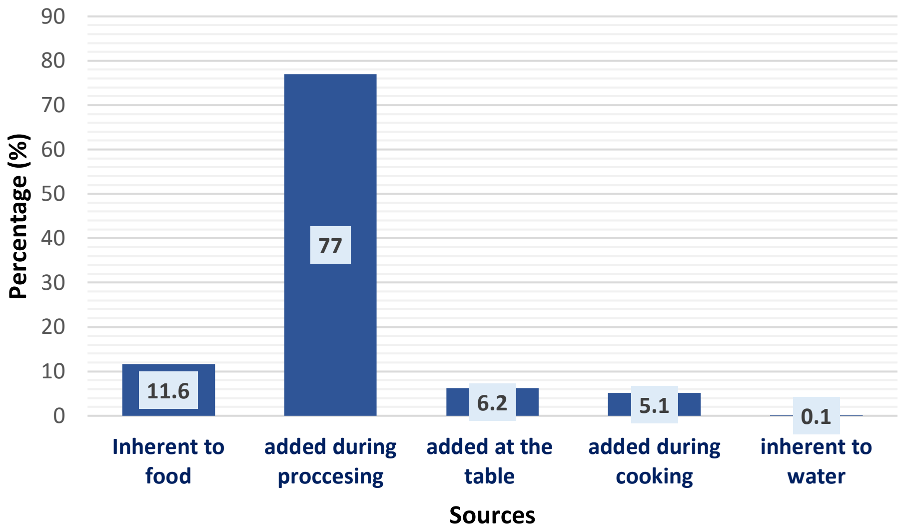

Figure 1. Sources of Sodium in the Diet [37].

Bread contributes significantly to sodium intake across multiple countries, with different proportions observed: 25.9% in Ireland, 25.5% in Turkey, 24.8% in Belgium, 24.2% in France, 19.1% in Spain, and 19% in the UK. Romania reports an even higher percentage 30% making it a leading source of dietary sodium in the country [38].

Consumer studies suggest that the preferred salt concentration in white wheat bread falls between 1.29% and 1.43%, while in Argentina, preferences tend to be higher at around 1.74%, possibly due to regional tastes. Bread's sodium content varies across Europe. In France, traditional breads such as country-style loaves and baguettes contain about 1.7% salt, whereas pastries and sweet baked goods have lower amounts, averaging between 1% and 1.3%. In the UK, salt levels in standard white and brown bread hover around 1%, while fruit buns, simple cakes, and fruited cakes contain between 0.32% and 0.72% [39].

Salt concentrations in bread differ from country to country. In Ireland, white bread contains 1.10% salt, while brown bread has 1.09%. German bread and rolls vary significantly, ranging from 1% to 2.9%. In Italy, artisanal bread shows a wide range of salt content, between 0.7% and 2.3%, while industrial bread falls between 1.1% and 2.2%. Spanish bread generally contains 1.63% salt, regardless of type. Romania's bread selection also exhibits significant variation, with non-salted bread containing as little as 0.17% salt, while potato bread reaches 1.79%. The salt concentration in bread depends largely on the type. Baguettes tend to have lower levels of salt, whereas potato bread has notably high concentrations. Among Romanian consumers, the most popular bread is refined wheat flour bread, an affordable option with an average salt content of 1.25% [40].

In Moldova bread is the largest contributor to sodium intake in the country, with 100 g of bread containing around 1.85 g of salt. More than half of Moldovans eat bread 2 to 3 times a day, with rural residents consuming it more frequently than urban dwellers.

High salt intake in Moldova has been directly linked to hypertension and cardiovascular diseases, which account for over 57% of all deaths nationwide. To combat this issue, the government has launched initiatives aimed at reducing salt consumption by 30%, bringing the daily intake below 8 g/day [32].

Interestingly, recent studies have explored alternative approaches to reduce salt in bakery products without compromising taste. Research on Grissini sticks revealed that using kefir, whey, and fermented borscht as substitutes for salt helped maintain flavor while significantly lowering sodium levels. These findings suggest that Moldova could incorporate traditional fermented liquids into baking practices to create healthier alternatives [41].

Table 1

Sodium Content in Bakery Products [42]

Category	Product Type	Sodium Content (mg/100g)
Bread	White Bread (UK)	400–500
	Brown Bread (UK)	380–480
	French Baguette	650–750
	Country-Style Bread (France)	650–750
	Industrial Bread (Italy)	400–800
Pastries	Croissant (France)	250–350
	Puff Pastry	200–300
Specialty	Potato Bread (Romania)	700–800
	Non-Salted Bread (Romania)	50–100
	Moldovan Bread	~750

Bakery products contribute significantly to daily sodium intake across Europe, with bread being a primary source. The sodium content varies by type and country (Table 1), with standard bread containing 400-750 mg/100 g**,** while pastries like croissants and puff pastry have lower levels (200-350 mg)**.** Romanian potato bread and Moldovan bread show some of the highest sodium concentrations, exceeding 700 mg/100 g, whereas non-salted bread offers a low-sodium alternative. Countries with traditional bread recipes, such as France, Romania, and Moldova, tend to have higher sodium levels [42].

Aleš et al. examine whether consumer perception of salt modification in bread is primarily a sensory or behavioral phenomenon. Given the significant role of salt in food manufacturing - affecting both technological and sensory properties - reducing sodium intake is a key public health strategy. However, producers often hesitate to lower salt levels, fearing negative consumer reactions and potential sales declines. The research assessed consumer hedonic liking and perceived saltiness intensity using two market-leading bread types (white and multigrain) with standard, reduced (-15%), and increased (+10%) salt levels. Results showed that while perceived saltiness remained largely unchanged, a 15% reduction influenced preference for multigrain bread. Penalty analysis revealed that suboptimal salt levels negatively impacted hedonic appreciation, emphasizing the importance of maintaining sensory appeal. Consumer segmentation further highlighted significant differences in preferences, underscoring the need for tailored reformulations [43].

3. Technological functions of salt in baking

Sodium chloride (NaCl), commonly known as salt, is a versatile ingredient widely utilized in households, the food service industry, and large-scale food production. Salt has many functions, it is an important ingredient due to its technological functions on the product, especially bakery products (Table 2) [9,44].

Table 2

The functions of salt in baking [9, 44]

Function	Description

Regulates Fermentation	Controls yeast activity, ensuring a steady rise and preventing excessive gas formation.
Strengthens Gluten	Reinforces protein bonds in flour, improving dough elasticity and preventing collapse during baking.
Enhances Flavor	Balances sweetness and acidity, amplifying the natural taste of ingredients without overpowering them.
Controls Enzyme Activity	Modulates enzymatic reactions to maintain dough consistency and prevent undesirable breakdowns.
Improves Browning	Facilitates caramelization and Maillard reactions, contributing to a visually appealing crust.
Extends Shelf Life	Reduces microbial activity, slowing spoilage and maintaining freshness for longer periods.
Balances Moisture	Regulates water retention, preventing excessive dryness or stickiness in the final product.
Improves Dough Handling	Enhances dough cohesion, making it easier to shape, roll, and manipulate during preparation.
Enhances Texture	Contributes to a uniform crumb structure, ensuring a soft yet stable baked good.
Prevents Over-Acidity	Maintains pH balance, preventing excessive sourness and ensuring a well-rounded flavor profile.

Salt plays a fundamental role in bread-making, influencing dough properties, fermentation, texture, flavor, and shelf life. Its impact begins at the structural level, where it strengthens gluten formation, allowing dough to retain gases and achieve a desirable crumb texture. By increasing osmotic pressure, salt regulates yeast activity, moderating gas production and preventing excessive fermentation, which helps maintain bread quality [45].

Beyond fermentation control, salt contributes to the sensory attributes of baked goods. It enhances flavor without making the product overtly salty, amplifying sweetness and balancing undesirable taste notes [46]. Additionally, sodium chloride helps optimize dough handling and rheological properties. Higher concentrations improve elasticity, viscosity, and overall dough stability, leading to firmer, less sticky dough that enhances machinability and final bread volume [47].

Salt's technological effects extend to water activity regulation, a critical factor in bread freshness and microbial stability. Controlling moisture migration between crumb and crust slows staling and inhibits spoilage organisms [48]. Bread's shelf life is closely linked to starch retrogradation, where amylose and amylopectin rearrange into insoluble structures, contributing to crumb rigidity and loss of elasticity [49]. Since bound water in staling bread accounts for approximately 70% of the total moisture, salt limits excessive hydration changes, preserving crumb softness for an extended period [50]. Studies indicate that reducing NaCl content from 1.2% to 0.3% shortens bakery product shelf life by nearly two days [51].

Salt also influences crust coloration. The Maillard reaction, responsible for browning during baking, relies on reducing sugars and amino acids, which are consumed more rapidly in low-salt dough due to intensified fermentation [52]. As a result, reduced-salt bread tends to have lighter crusts, lacking the rich golden-brown hue associated with optimal baking conditions. Furthermore, sodium chloride exerts a plasticizing effect, favoring Maillard reaction efficiency and contributing to deeper crust coloration and enhanced aroma [53].

In terms of yeast fermentation, salt controls microbial activity by modulating the availability of fermentable carbohydrates. A lower salt concentration accelerates yeast metabolism, consuming sugars required for browning and flavor formation [54.]. This increased metabolic rate leads to faster dough expansion and heightened loaf volume, though excessive yeast activity can result in open crumb structures and irregular porosity.

Sodium chloride significantly affects sensory perception, intensifying sweet flavors and suppressing bitterness. Studies show that gradual sodium reduction of up to 25% often goes unnoticed by consumers, whereas a 50% reduction alters taste perception considerably [55]. Low-salt bread is often described as sour or overly yeasty, as sodium contributes to the overall flavor balance. While sodium ions improve palatability, alternatives such as potassium and calcium tend to introduce undesirable metallic or bitter notes [56]. Furthermore, sodium ions interact with wheat proteins during dough formation, strengthening gluten networks and influencing baking performance. Research suggests that these ions are released during chewing, affecting salty taste perception depending on crumb structure and sodium levels [57].

Salt also plays a crucial role in texture development. By strengthening gluten bonds, it stabilizes fermentation rates, extends dough mixing time, and improves crumb porosity. Gas bubbles formed during dough preparation must maintain structural integrity throughout baking; salt supports this by optimizing gas retention, leading to bread with desirable elasticity and volume [58]. As sodium levels decrease, yeast activity increases, producing bread with a higher loaf volume but weaker structural integrity. At low salt concentrations (0.7–0.8%), yeast multiplication accelerates, while at higher levels, plasmolysis slows the process. Additionally, salt modulates enzyme activity, reducing proteolytic and amylolytic reactions that degrade gluten and starch, preventing excessive softening and gas loss [59,60].

A comparative study on bread texture found that formulations containing 4% salt exhibited crumb firmness values nearly 40% higher than salt-free bread after 24 hours, highlighting its structural impact. The firming effect arises from conformational changes in gluten proteins due to sodium chloride interaction. Additionally, alternative sodium reduction strategies such as potassium-based salts, enzymatic treatments, and fermentation adjustments help address technological challenges while maintaining quality. Innovations like inhomogeneous salt distribution allow up to a 28% reduction without compromising perceived saltiness [39].

Salt's impact on dough machinability is particularly relevant in industrial bakery settings. It improves dough resistance to tearing during mechanical processing, ensuring smooth sheeting and molding operations. Reduced salt levels can lead to stickier dough, complicating automated processing and requiring adjustments in mixing techniques.

Furthermore, salt plays a role in gas bubble stability during proofing and baking. A well-developed gluten network, reinforced by sodium chloride, enhances gas retention, leading to a uniform crumb structure and preventing excessive collapse. This effect is crucial for maintaining bread volume and texture consistency [61].

Salt also affects baking losses, influencing moisture retention during baking. Lower salt levels may lead to increased evaporation, affecting the final weight of the product. Maintaining optimal salt concentrations ensures better yield and product consistency.

From a sensory perspective, sodium chloride contributes to the perception of texture and mouthfeel. It interacts with wheat proteins, modifying hydration properties and influencing the balance between free and bound water. This interaction affects dough extensibility, elasticity, and overall baking performance [62].

Lastly, salt alternatives and their challenges remain a critical area of research. While potassium-based salts and other substitutes can mimic some of sodium chloride's effects, they often introduce undesirable flavors or fail to replicate its full functionality in dough development. Future innovations in bakery science aim to refine sodium reduction strategies while preserving product integrity.

4. Optimization of sodium content in bakery products: methods and solutions

Reducing sodium in baked goods requires a multifaceted approach to balance health benefits with product quality and consumer acceptance. Excessive sodium reduction can impact dough rheology, fermentation, and shelf life, making it essential to employ strategies that preserve sensory appeal and functionality.

One of the most effective techniques is gradual salt reduction, where sodium levels are systematically lowered over time. Research suggests that a stepwise reduction of 5%/week can lead to a 25% sodium decrease in bread while remaining unnoticed by consumers [63,64]. Over time, individuals adapt to lower salt levels, which naturally reduces their preference for highly salted foods [65].

Salt replacers offer another effective method, with potassium chloride (KCl) being the most widely used alternative. By blending KCl with magnesium or calcium salts, manufacturers can achieve up to 32% sodium reduction in bread while maintaining sensory appeal [66]. Additionally, replacing up to 30% NaCl with potassium salts preserves consumer preference while providing bioavailable potassium, which supports cardiovascular health [67].

For bread formulations, incorporating sourdough helps counteract the negative effects of salt reduction by improving flavor complexity, dough rheology, and shelf life. The fermentation process enhances texture and contributes to a more balanced taste profile, making it a valuable tool in sodium-reduced baked products [68].

To further enhance perceived saltiness, flavor enhancers like yeast extracts, glutamates, and potassium salts are commonly used. Studies indicate that these ingredients can compensate for flavor loss when salt is reduced by up to 67%, ensuring that low-sodium formulations remain appealing to consumers [69]. Another approach, heterogeneous salt distribution, strategically places varying salt concentrations within a product to amplify salt perception at lower sodium levels.

Beyond ingredient substitutions, innovative processing techniques help manufacturers reduce sodium while maintaining dough properties. Methods such as ozonated water treatment and mechanical leavening via cavitation technology enable sodium reduction in cupcakes and other baked goods without affecting product structure [70].

While sodium reduction must be carefully managed to maintain product integrity, consumer acceptance plays a crucial role. Research suggests that some methods, such as salt replacers and taste enhancers, are more widely accepted than others. Additionally, pairing nutritional education with sodium-reduced bread significantly lowers daily sodium intake in adults, though the effects on children appear less pronounced.

Achieving effective sodium reduction in baked goods requires a strategic combination of gradual reduction, salt replacers, sourdough fermentation, flavor enhancers, and advanced processing techniques. When implemented methodically, these approaches allow manufacturers to create healthier baked goods while maintaining sensory appeal, shelf stability, and consumer preference.

4.1. The effect of using potassium chloride as a substitute for sodium in bakery products

KCl, known for its natural salty flavor, serves as a viable alternative to sodium salt in food applications. Its ability to replicate the functional properties of NaCl makes it a promising option for reducing sodium intake while maintaining taste integrity. KCl has been extensively investigated as an alternative to NaCl in bakery formulations, with the goal of lowering sodium levels in the diet due to their association with conditions such as high blood pressure. Studies have examined how replacing NaCl with KCl influences the functional characteristics of dough, the final quality of baked goods, taste perception, and the potential health outcomes - particularly for groups requiring controlled sodium intake [71].

Before evaluating the feasibility of replacing sodium with KCl in bakery formulations, it is essential to first examine its effects on human health. Table 3 presents a summary of the key benefits and potential risks associated with KCl consumption, providing a foundation for understanding its physiological impact and suitability as a sodium alternative in food product.

Table 3

Effects of KCl on human health [72-75]

Characteristics	Positive effects	Negative effects
Blood pressure regulation	Helps lower hypertension by counteracting sodium's effects.	Excessive intake may disrupt heart function.
Muscle function	Supports muscle contractions and prevents cramps.	High levels can cause weakness or irregular heartbeats.
Nervous system health	Essential for nerve signal transmission and cellular communication.	Can lead to hyperkalemia in individuals with kidney disease.
Stroke prevention	Linked to a lower risk of strokes with adequate intake.	Excessive amounts may stress kidney function.
Fluid balance	Helps regulate hydration and cellular processes.	May cause digestive discomfort (nausea, diarrhea) when taken in excess.

For optimal health, adult men require 3.4 g of potassium/day, while women need 2.6 g/day. Pregnant individuals benefit from a slightly higher intake of 2.9 g/day, whereas lactating women should aim for 2.8 g/day to support both maternal and infant nutritional needs. In cases of hypokalemia (potassium deficiency), medical guidelines suggest 40-100 mEq/day, depending on severity and individual health status. However, excessive potassium intake can lead to hyperkalemia, a condition that disrupts normal heart function and poses risks, particularly for individuals with kidney disorders. Careful monitoring and adherence to dietary recommendations are essential to prevent adverse health effects [72-74].

KCl stands out as a valuable alternative to traditional salt (NaCl) in food production, offering comparable functional benefits. However, its use presents challenges, particularly in terms of taste, as it can introduce bitter, metallic, or acrid notes that may be undesirable. To address these sensory drawbacks, various strategies have been explored, including the incorporation of flavor-enhancing compounds and specialized formulation techniques designed to improve palatability while maintaining the desired properties of salt replacements [75].

Antúnez et al. examine the partial replacement of NaCl with KCl in bread to reduce sodium intake while maintaining sensory acceptability. Given the health risks associated with excessive sodium consumption, KCl is explored as an alternative without compromising taste and functionality. The research evaluates the impact of this substitution on sensory characteristics and consumer perception. Findings indicate that while sodium reduction is essential for public health, acceptance remains a challenge. A 30% reduction in NaCl did not significantly alter sensory attributes, but a 40% reduction led to bitterness and metallic notes. The balance between health benefits and sensory appeal is crucial to ensuring consumer satisfaction [76].

Another study by Chen et al investigates the role of KCl as a partial substitute for NaCl in wheat dough and bread. Dough samples with varying KCl concentrations (0–2%, fwb) were analyzed through physical and rheological tests using Mixograph, TA XT2 Texture Analyzer, and Bohlin CVOR 150 Rheometer. Additionally, gluten and starch microstructures were examined using Zeta Potential Analyzer, RP-HPLC, FTIR, spectrophotometry, and differential scanning calorimetry. Findings reveal that KCl enhances dough elasticity and strength while reducing stickiness, closely mimicking the effects of NaCl without compromising overall dough and bread quality. These results suggest that substituting NaCl with KCl could be an effective strategy to lower sodium intake while maintaining product integrity. However, further research is needed to refine sensory attributes and optimize consumer acceptance [71,77].

Rodrigues et al. investigate the feasibility of using KCl as a substitute for NaCl in bread production. Researchers analyzed its impact on dough rheology, bread texture, and sensory acceptability, aiming to establish the threshold at which KCl can replace NaCl without being detected by consumers [78].

KCl is increasingly used as a partial replacement for NaCl in bakery formulations, given the growing demand for sodium reduction in food products. However, the extent to which KCl can replace NaCl depends on various technological and sensory factors (Table 4).

At low substitution levels (up to 25%), KCl does not significantly alter dough rheology, and the bread maintains its typical structural integrity and volume. The sensory profile remains close to that of traditional formulations, with minimal taste differences. This level of substitution is widely accepted and commonly used in sodium reduction strategies.

At moderate substitution levels (25–50%), the dough begins to show slight weakening in gluten structure, affecting extensibility and elasticity. The texture and shelf life may be impacted, requiring formulation modifications such as enzyme treatments or fermentation adjustments to compensate for changes. Sensory differences become more noticeable, with a mild bitterness that may influence consumer preference. Many commercial applications blend KCl with other salts or flavor enhancers to mask these effects.

At high substitution levels (above 50%), significant disruptions in dough rheology occur. Bread made with a high proportion of KCl experiences reduced loaf volume, irregular crumb structure, and decreased gas retention capacity. Additionally, bitterness becomes more pronounced, negatively impacting consumer acceptance. Advanced formulation strategies, such as enzymatic treatments, sourdough fermentation, or aroma-enhancing techniques, may be required to mitigate undesirable taste attributes [79].

Results indicate that KCl can substitute up to 0.92% of the standard 2% NaCl content while remaining unnoticed in terms of taste. However, reducing NaCl led to lower dough elasticity, reduced bread volume, firmer texture, faster staling, and a lighter crust.

Table 4

The dosage and effects of KCl substitution in bakery products [79, 80]

Substitution level	Effect on dough properties	Impact on bread quality	Sensory acceptability	Additional considerations

Up to 25% KCl	Minimal impact on gluten development and fermentation.	Maintained structure and volume.	Similar to NaCl	Commonly used in sodium reduction strategies.
25–50% KCl	Slight weakening of gluten network, requiring formulation adjustments.	Possible minor changes in texture and shelf life.	Some bitterness detected.	Often blended with other salts to improve taste.
Greater than 50% KCl	Noticeable impact on dough elasticity and fermentation rate.	Reduced loaf volume and altered crumb structure.	Increased bitterness, lower consumer acceptance.	Requires masking agents or enzymatic treatments.

Despite these effects, formulations where up to 50% of NaCl was replaced with KCl maintained comparable technological properties and consumer acceptance**,** offering a promising alternative for sodium reduction [80].

Similarly, Chen et al. found that KCl influences dough elasticity and strength, closely mirroring NaCl's effects without compromising quality. Rheological tests, including Mixograph and Bohlin CVOR 150 Rheometer analysis, demonstrated that KCl effectively maintains dough structure while reducing stickiness [71,77].

Research of Charlton et al. further analyzed the combined effects of potassium and magnesium salts**,** showing they affect dough stability and elasticity while certain ingredients, like sugar and milk, help mask off-flavors [81].

These findings underscore the promising role of KCl as a sodium-reducing agent in bakery formulations, demonstrating its ability to preserve essential quality parameters such as dough handling, crumb structure, and overall product integrity. However, despite its technical functionality, further optimization is needed - particularly in terms of sensory characteristics—to minimize any bitterness or off-flavors associated with KCl and to ensure that consumer acceptance remains high across diverse population groups with varying taste sensitivities and cultural preferences.

4.2. The effect of using sourdough as a substitute for sodium in bakery products

Sourdough, also known as natural leaven, is a fermented blend of flour and water containing wild yeast and lactic acid bacteria. Unlike commercial yeast, sourdough relies on natural fermentation to leaven bread, creating a distinct flavor, chewy crumb, and crispy crust. It is slow fermentation process enhances digestibility, reduces gluten content, and increases nutrient bioavailability.

Rich in lactic acid bacteria, sourdough supports gut health (Table 5) and contributes to a balanced microbiome. It also has a lower glycemic index, making it a favorable option for blood sugar control. Additionally, sourdough's acidic environment acts as a natural preservative, extending shelf life without artificial additives [82].

Sourdough used in bakery products varies in hydration, flour type, and fermentation duration, influencing dough elasticity, flavor complexity, and shelf life. Liquid sourdough accelerates fermentation and creates a lighter texture, while solid sourdough ensures a deeper flavor and controlled fermentation. Whole grain and rye sourdough promote more active fermentation due to their nutrient-rich composition, while adjustments in hydration affect gluten development and overall product structure. Choosing the right sourdough type depends on the desired sensory and technological characteristics, ensuring optimal baking performance and consumer appeal [82].

Table 5

Effects of sourdough on human health [48, 83]

Characteristics	Positive effects	Negative effects
Digestibility	Fermentation breaks down gluten and phytic acid, improving nutrient absorption and making bread easier to digest.	Not completely gluten-free, which may cause issues for individuals with celiac disease.
Gut Health	Contains beneficial lactic acid bacteria that support a balanced microbiome and aid digestion.	Some individuals may experience bloating or discomfort due to fermentation byproducts.
Glycemic response	Lower glycemic index compared to conventional bread, helping regulate blood sugar levels.	Still contains carbohydrates, which may impact blood sugar if consumed in excess.
Nutrient profile	Rich in essential vitamins and minerals such as calcium, potassium, magnesium, and folate.	Nutrient levels vary depending on flour type and fermentation duration.
Antioxidant properties	Fermentation enhances antioxidant levels, potentially reducing inflammation and supporting overall health.	Acidic nature may be problematic for individuals with acid reflux or sensitive digestion.

Cutting down on sodium in bakery products is a key health priority, but it can compromise taste, texture, and shelf life. An effective way to balance these challenges is by incorporating sourdough as a partial substitute for sodium. This approach not only enables a significant reduction in sodium content but also enhances the product's flavor, texture, and overall quality. Additionally, the natural fermentation of sourdough brings benefits like improved digestibility and a longer shelf life, making it a valuable option in modern baking [48,83].

Sourdough is widely recognized for its ability to enhance bread quality, texture, and shelf life, while catering to growing consumer demand for natural and flavorful foods [84]. Sourdough fermentation plays a crucial role in bread quality, texture, and shelf life, offering advantages in dough development and biochemical interactions [85].

A key advantage of sourdough is its role in sodium reduction, as its inherent acidity can intensify perceived saltiness, potentially lowering the need for added sodium [86].

Despite this, NaCl remains fundamental in bakery products due to its role in fermentation control, water activity regulation, and dough rheology [87]. NaCl influences protein interactions, hydrophobic bonding, and biopolymer conformations, which directly affect dough development [88].

The inclusion of sourdough in wheat flour dough introduces notable changes, particularly through pH modulation, impacting structural elements like gluten, starch, and hemicellulose [89]. The acids present in sourdough also interact with flour enzymes, influencing proteolytic and amylolytic activity, further shaping dough properties [88,89].

From a technological perspective, sourdough can influence dough structure by weakening the gluten network and reducing stability compared to traditional sodium chloride. However, when used in moderate amounts, it maintains acceptable dough properties. Additionally, sourdough contributes positively to bread characteristics by mitigating some of the negative effects of salt reduction, such as diminished flavor and shorter shelf life. The production of organic acids and antifungal compounds within sourdough improves sensory qualities and extends microbial shelf life [90].

Table 6

The dosage and effects of sourdough substitution in bakery products [91]

Substitution level	Effect on dough properties	Impact on bread quality	Sensory acceptability	Additional considerations
25% Sourdough	Slight increase in dough extensibility; minimal impact on gluten network.	Mild enhancement in flavor complexity; slight acidity.	Well accepted, subtle sourdough notes.	Requires minor hydration adjustments to maintain dough consistency.
50% Sourdough	Noticeable changes in fermentation dynamics; softer dough structure.	Improved aroma and crumb texture; moderate acidity.	Generally acceptable, though acidity becomes more pronounced.	Longer fermentation needed for optimal results; potential impact on yeast activity.
75% Sourdough	Significant reduction in sodium; increased dough elasticity.	Softer crumb, extended shelf life; distinct sourdough flavor.	Acceptability varies based on consumer preference.	Adjustments in mixing and proofing times required; acidity may affect dough strength.
100% Sourdough	Full sodium replacement; requires careful fermentation control.	Strong sourdough taste; softer texture; longer shelf life.	May be too acidic for some consumers.	Requires balancing acidity with fermentation duration; potential need for enzyme or hydration adjustments.

The substitution of sodium with sourdough significantly influences dough behavior, bread texture, and sensory perception (Table 6). At lower replacement levels (25-50%), the impact is subtle-enhancing flavor complexity, introducing mild acidity, and improving dough softness without requiring major formulation changes. Higher substitution levels (75-100%) lead to more pronounced effects, including increased elasticity, extended shelf life, and a stronger sourdough taste, necessitating careful fermentation management and hydration adjustments. Sensory acceptance varies, with moderate substitutions generally well-received, while full replacement may be too acidic for some consumers [91]. Balancing sodium reduction with dough strength and fermentation control is essential for optimizing formulation.

Studies have shown that up to 45% sodium reduction in products like French rolls is achievable when incorporating less than 5% dry sourdough, without compromising volume, shape, or texture. Moreover, sourdough fermentation naturally enhances bread flavor, masking the blandness that often results from lower sodium levels [90].

Functional sourdoughs, enriched with specific lactic acid bacteria, significantly improve the shelf life of low-sodium breads by generating beneficial compounds such as exopolysaccharides and antifungal substances [48].

These insights underscore sourdough's dual benefits-enhancing sensory appeal while supporting sodium reduction strategies. However, optimizing its role requires balancing fermentation dynamics and dough structure to maintain product quality in reduced-sodium formulations.

Nogueira et al. examined dry sourdough as a potential alternative to NaCl in wheat flour dough, given NaCl's impact on dough rheology and bread quality. Using a central composite rotatable design, varying levels of NaCl (0-2.5 g/100 g) and dry sourdough (0-10 g/100 g) were tested. Results showed opposing effects between NaCl and sourdough on farinograph and extensograph properties, while pasting characteristics were minimally affected. Despite this, optimal formulations were identified, proving that sodium reduction is achievable without compromising dough functionality. This research highlights dry sourdough's potential in creating lower-sodium bakery products while maintaining technological performance [90].

Overall, this approach offers a valuable solution for bakers seeking to create healthier products without sacrificing taste or quality, positioning sourdough as an effective strategy in modern bakery formulations.

4.3. The effect of using flavor enhancers as a substitute for sodium in bakery products

Flavor enhancers are natural or synthetic compounds used in the food industry to intensify and amplify the existing taste of ingredients without introducing a new flavor profile. Unlike artificial flavorings, which add distinct tastes, flavor enhancers work by boosting the perception of the food's inherent flavors, making them more pronounced and enjoyable.

Flavor enhancers influence human health in both beneficial and harmful ways, depending on their type and consumption levels. On the positive side, they improve taste perception, making food more enjoyable and encouraging better nutrition, particularly for individuals with reduced appetite. They also support sodium reduction, allowing for lower salt content in foods while maintaining palatability. Some umami compounds have been linked to immune function support and improved oral health.

However, excessive consumption of artificial enhancers presents certain health risks. Some individuals may experience neurological effects, such as headaches or sensitivity reactions, particularly with monosodium glutamate. Long-term intake of synthetic enhancers has been associated with metabolic concerns, including obesity, liver stress, and inflammation. While regulatory agencies generally consider them safe, prolonged exposure may contribute to hormonal imbalances and other systemic health effects [4,92].

Flavor enhancers offer a promising solution, effectively masking reduced salt levels, maintaining sensory qualities, and even providing additional benefits related to food safety. Flavor enhancers help maintain taste and texture in reduced-sodium products while also playing a role in food safety by limiting microbial growth, extending shelf life, and improving product stability. Certain enhancers, like yeast extracts and nucleotides, offer additional nutritional benefits by introducing valuable compounds. Their ability to refine flavor ensures that low-sodium formulations remain both desirable and effective, catering to health-conscious consumers and advancing industry innovation [39].

Flavor enhancers include (Table 7) umami compounds, which deepen savory taste, natural additives that balance overall flavor, yeast extracts rich in glutamates, taste peptides that amplify sensory perception, and odor compounds that shape aromatic profiles, all working together to refine and enhance food formulations.

Table 7

The dosage and effects of flavor enhancers substitution in bakery products [93-95]

Flavor enhancer	Effect on dough properties	Impact on bread quality	Sensory acceptability	Additional considerations

Yeast extracts	Improves dough extensibility and fermentation activity.	Enhances umami notes and depth of flavor.	Well accepted, commonly used in reduced-sodium formulations.	Can replace some salt functionality but may require adjustments in hydration.
MSG	Minimal effect on dough structure.	Strengthens savory taste, making bread flavors more pronounced.	Generally accepted but may be avoided due to consumer concerns.	Regulatory limits may apply depending on the region.
Nucleotides IMP & GMP	Supports dough stability and gluten network.	Boosts complex savory and meaty flavors in bread.	High acceptability, synergizes well with yeast extracts.	Often used in combination with other enhancers for balanced taste.
Malt extracts	Improves dough elasticity and fermentation control.	Adds subtle sweetness and depth to bread.	Well accepted, enhances natural cereal flavors.	Works best with whole grain formulations.
Fermented soy compounds	Enhances dough hydration and enzyme activity.	Provides mild saltiness and umami-like richness.	Generally well received, particularly in artisanal formulations.	Can complement sodium reduction strategies in bakery applications.

Note: MSG - monosodium glutamate; IMP- inosine monophosphate; GMP - guanosine monophosphate.

One of the primary concerns with sodium reduction is ensuring that the final product remains palatable. Studies show that ingredients such as poppy seeds, sesame seeds, and fermented soy compounds can successfully mask the decrease in saltiness, maintaining consumer preference and product acceptability.

For example, bread in which 25% of sodium was replaced with a fermented soy-based flavor enhancer received consumer ratings similar to traditional bread made with regular salt [93]. Likewise, savory shortbread containing poppy or sesame seeds was highly rated by consumers, confirming their effectiveness in preserving product appeal despite reduced sodium levels [94].

Certain glutamate-based enhancers such as MSG and magnesium glutamate (MAG) demonstrate remarkable efficacy in boosting perceived saltiness, even when sodium chloride is reduced. These compounds outperform nucleotide-based enhancers like IMP and GMP in maintaining the sensory perception of salt across various levels of sodium reduction [95].

However, studies indicate that the effectiveness of flavor enhancers is greatest when sodium reduction remains moderate rather than extreme (Table 8). This suggests that a balance between sodium reduction and flavor enhancement must be maintained to optimize both taste and health benefits [4].

Beyond taste modification, some flavor enhancers contribute to food safety by reducing specific contaminants.

Table 8

Examples of flavor enhancers and dosage of use [94-95]

Flavor enhancer	**Function**	**Typical dosage, %**

MSG	Enhances umami and salty taste perception.	0.1–0.8
MAG	Boosts savory flavor with a mineral profile.	0.1–0.5
Yeast extract	Provides depth and saltiness in formulations.	0.5–2
Soy sauce powder	Adds rich umami and saltiness.	1–3
Miso paste	Deepens flavor, commonly used in baked goods.	2–5
IMP & GMP	Works synergistically with glutamates to intensify umami	0.05–0.2
Poppy seeds & sesame seeds	Mask reduced salt levels, enhance texture.	2–5
Onion & garlic powder	Adds savory notes, may impact food safety processes.	0.5–3

Note: MSG - monosodium glutamate; MAG - magnesium glutamate; IMP- inosine monophosphate; GMP - guanosine monophosphate.

For instance, poppy and sesame seeds accelerate the breakdown of harmful compounds such as monochloropropanediol esters and glycidyl esters, potentially improving product safety. In contrast, other enhancers including onion and garlic, may slow this process, highlighting the importance of strategic ingredient selection [94].

Moreover, fermented soy-based enhancers can impact the physical characteristics of baked goods, such as crumb color, crust darkness, and loaf volume. However, when used at moderate substitution levels, these changes do not negatively affect consumer preference, ensuring the final product remains appealing [93].

Flavor enhancers represent a valuable tool in reducing sodium content in bakery products without compromising taste or texture. By carefully selecting ingredients such as glutamate-based enhancers, fermented soy compounds, and seed-based additions, manufacturers can create healthier formulations while maintaining consumer satisfaction. Balancing sodium reduction with appropriate sensory modifications is key to achieving both nutritional benefits and high-quality baked goods.

5. Conclusions

Salt plays a multifunctional role in bakery products, influencing their sensory appeal, structural integrity, and technological properties. It enhances flavor by balancing sweetness and intensifying taste perception, while also strengthening the gluten network, improving dough elasticity and extensibility. Additionally, salt regulates yeast activity, ensuring controlled fermentation and preventing excessive gas formation.

Beyond taste and texture, it contributes to crust formation through the Maillard reaction, giving baked goods their characteristic golden-brown appearance, while its preservative properties help extend shelf life by inhibiting microbial growth.

Given its critical role, reducing sodium in bakery products requires careful formulation strategies to maintain product quality. KCl serves as a partial substitute, offering similar functional benefits, but its metallic or bitter taste necessitates adjustments or combinations with other compounds to improve palatability.

Another effective approach is sourdough fermentation, which enhances both texture and flavor while contributing to a more nutritionally rich product. The organic acids and complex flavor compounds produced during fermentation intensify taste perception, reducing the need for excessive salt while improving dough elasticity and strength. Additionally, sourdough contributes to moisture retention, prolonging shelf life and improving the overall eating experience.

Flavor enhancers provide an additional strategy for sodium reduction, compensating for lower salt content by reinforcing taste perception. Ingredients such as yeast extracts, glutamates, hydrolyzed vegetable proteins, nucleotides, amino acids, and fermented sugars amplify savory flavors, ensuring a balanced and enjoyable sensory experience without excessive sodium levels. However, these enhancers have minimal technological effects, requiring careful formulation to maintain dough structure and fermentation dynamics.

To successfully implement sodium reduction strategies on an industrial scale, manufacturers must optimize formulations, adjust processing methods, and educate consumers on the benefits of reduced sodium intake. Combining alternative salts, sourdough, and taste enhancers allows for significant sodium reduction while preserving or even enhancing product quality. Future innovations, such as encapsulation techniques and controlled salt distribution, will further refine these approaches, ensuring that low-sodium bakery products meet both technological and sensory expectations while aligning with health recommendations.

Additionally, consumer adaptation plays a crucial role in the success of sodium reduction strategies. Gradual reductions in salt content allow consumers to adjust their taste preferences over time, minimizing resistance to lower-sodium formulations. Sensory trials and market research help manufacturers fine-tune recipes to ensure optimal acceptance while maintaining product integrity.

Ultimately, the future of low-sodium bakery products depends on continued research and innovation, integrating technological advancements, ingredient optimization, and consumer education to create healthier, high-quality baked goods that align with global health recommendations.

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References

1. Kourkouta, L.; Koukourikos, K.; Iliadis, C.; Ouzounakis, P.; Monios, A.; Tsaloglidou, A. Bread and Health. *Journal of Pharmacology* 2017, 5, pp. 821-826.
2. Yan, Y.Y.; Chan, L.M.L.; Wang, M.P.; Kwok, J.Y.Y.; Anderson, C.S.; Lee, J.J. Technology-supported behavior change interventions for reducing sodium intake in adults: a systematic review and meta-analysis. *NPJ Digital Medicine* 2024, 7, 72.
3. World Health Organization. Guideline: Sodium Intake for Adults and Children. (World Health Organization, 2012). Available online: https://www.who.int/publications/i/item/9789241504836 (accessed on 27.04.2025).
4. Codină, G.G.; Voinea, A.; Dabija, A. Strategies for Reducing Sodium Intake in Bakery Products, a Review. *Appl. Sci*. 2021, 11, 3093.
5. Khan, A.W.; Roobab, U.; Wang, Z.; Raza, M.M.; Nawazish, H.; Islam, F.; Aadil, R.M. Salt reduction in food products: A systematic review of clean-label ingredients and non-thermal technologies. *Trends Food Sci. Technol*. 2024, 153, 104695.
6. Siminiuc, R.; Ţurcanu, D. Development of a model for evaluating the nutritional quality of bread and bakery products, *Journal of Food and Nutrition Research* 2024, 63(2), pp. 155-164
7. WHO Global Report on Sodium Intake Reduction. (World Health Organization, 2023). Available online: https://www.who.int/publications/i/item/9789240069985 (accessed on 27.04.2025).
8. Arendt, E.; Ryan, L.; Belz, M.C.E. The impact of salt reduction in bread: A review. *Crit. Rev. Food Sci. Nutr.* 2012, *52*, 514–524.
9. Man, C.M.D. *Technological Functions of Salt in Food Products*. Wiley, London, UK, 2007, pp. 157–173.

10. Albarracín, W.; Sánchez, I. C.; Grau, R.; Barat, J. M. Salt in food processing; usage and reduction: a review. *International Journal of Food Science & Technology* 2011,46 (7), pp.1329–1336.
11. Mannar, M.G.V.; Hurrell, R.F. Food Fortification in a Globalized World. 1st ed. London: Academic Press, 2018, pp. 143–151.
12. Munteanu, C.; Iliuta, A. The role of sodium in the body. *Balneo Res. J.* 2011, 2, pp.70–74.
13. European Union. Regulation (EU) 2017/1529 on legal provisions. Official Journal of the European Union. Available online: https://eur-lex.europa.eu/legal-content/RO/TXT/PDF/?uri=CELEX:32017R1529 (accessed on 25.05.2025).
14. Agulheiro-Santos, A.; Laranjo, M.; Potes, M.; Elias, M. The Role of Salt on Food and Human Health. *Salt in the Earth*. IntechOpen, London, United Kingdom, 2019, pp. 10-20.
15. Grillo, A.; Salvi, L.; Coruzzi, P.; Salvi, P.; Parati, G. Sodium Intake and Hypertension. Nutrients, 2019, 11(9), 1970.
16. O'Donnell, M.; Mente, A.; Yusuf, S. Sodium intake and cardiovascular health. *Circulation research* 2015, 116(6), pp. 1046-1057.
17. Chrysant, S.G. There are not racial, age, sex or weight differences in the sensitive hypertensive patients. *Arch. Intern. Med*. 1997, 157, pp. 2489–2494.
18. Doyle, M.E. Sodium Reduction and Its Effects on Food Safety, Food Quality, and Human Health: A Brief Review of the Literature. Food Research Institute, University of Wisconsin–Madison, 2008, pp. 2-10.
19. Logan, A. Dietary Sodium Intake and Its Relation to Human Health: A Summary of the Evidence. *Journal of the American College of Nutrition* 2006, 25, pp. 165-169.
20. Israr, T.; Rakha, A.; Sohail, M.; Rashid, S.; Shehzad, A. Salt reduction in baked products: Strategies and constraints. *Trend in Food Science and Tehnology* 2016, 51, pp. 98-105.
21. Whelton, P.K.; He, J. Health effects of sodium and potassium in humans. *Curr. Opin. Lipidol*. 2014, 25, pp. 75–79.
22. Turck, D.; Castenmiller, J.; De Henauw, S.; Hirsch-Ernst, K.; Kearney, J.; Knutsen, H.; Maciuk, A.; Mangelsdorf, I., Mcardle, H.; Peláez, C.; Pentieva, K.; Siani, A.; Thies, F.; Tsabouri, S.; Vinceti, M.; Aggett, P.; Fairweather-Tait, S.; Martin, A.; Przyrembel, H.; Ciccolallo, L.; De Sesmaisons-Lecarré, A.; Martínez, S.; Martino, L.; Naska, A. Dietary reference values for sodium. *EFSA Journal*, 2019, 18(11), e06304.
23. Hunter, R.W.; Dhaun N.; Bailey M., A. The impact of excessive salt intake on human health. *Nature Reviewes Nephrology*, 2022, 18, pp. 321-332.
24. Cook, N.R.; He, F.J.; MacGregor, G.A. Sodium and health - concordance and controversy. *The BMJ*. 2020, 369.
25. Jelaković, B.; Glavić, M.; Sermek, M.; Bilajac, L.; Bubaš, M.; Služek, V.; Capak, K.; Drenjančević, I.; Bošković, A.; Jelaković, A.; Jukić, T.; Kravar, S.; Kralj, V.; Pećin, I.; Pollak, L.; Skoko-Poljak, D.; Stražanac, D.; Stupin, A.; Vasiljev, V.; Vidranski, V.; Reiner, Ž. Croatian Action on Salt and Health (CRASH): On the Road to Success—Less Salt, More Health. *Nutrients* 2024, 16, 1517.
26. Rosewarne, E.; Santos, J.; Trieu, K.; Tekle, D.; Mhurchu, C.; Jones, A.; Ide, N.; Yamamoto, R.; Nishida, C.; Webster, J. A Global Review of National Strategies to Reduce Sodium Levels in Packaged Foods. *Advances in nutrition* 2022, 13(5), pp. 1820–1833.
27. Commission Regulation (EU) No 1129/2011 of 11 November 2011. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011R1129 (accessed on 01.05.2025).
28. Fedima proposes a new regulatory framework in the EU. Available online: https://www.roaliment.ro/stiri-industria-alimentara/fedima-propune-un-nou-cadru-de-reglementare-pentru-industria-panificatiei-in-ue/ (accessed on 01.05.2025) [in Romanian].
29. Allemandi, L.; Tiscornia, M.; Ponce, M.; Castronuovo, L.; Dunford, E.; Schoj, V. Sodium content in processed foods in Argentina: compliance with the national law. *Cardiovascular diagnosis and theraphy*, 2015, 5(3), pp. 197-206.
30. Kloss, L.; Meyer, J.; Graeve, L.; Vetter, W. Sodium intake and its reduction by food reformulation in the European Union - A review. *NFS Journal* 2015, 1, pp. 9-19.
31. Vandevijvere, S. Sodium reduction and the correction of iodine intake in Belgium: Policy options. *Archives of Public Health* 2012, 70, 10.
32. Study shows Moldovans consume double the recommended salt intake. Available online: https://www.who.int/europe/news/item/22-11-2018-study-shows-moldovans-consume-double-the-recommended-salt-intake (accessed on 01.05.2025)

33. Change your habit of adding salt to ready-made meals! - during Salt Reduction Awareness Week. Available online: https://ansp.md/schimba-ti-obiceiul-de-a-adauga-sare-in-bucatele-gata-in-saptamana-de constientizare-a-reducerii-consumului-de-sare/ (accessed on 01.05.2025) [in Romanian].
34. Three informative sessions on reducing salt consumption, held as part of the event "Less salt in food". Available online: https://ms.gov.md/comunicare/comunicate/trei-sesiune-informative-cu-privire-la-reducerea-consumului-de-sare-desfasurate-in-cadrul-mai-putina-sare-in-mancare/ (accessed on 01.05.2025) [in Romanian].
35. Meeting between ANPC and representatives of ROMPAN and ANAMOB from the bakery industry to improve compliance with legal regulations ANPC. Available online: https://anpc.ro/intalnire-intre-anpc-si-reprezentantii-rompan-si-anamob-din-industria-de-panificatie-pentru-imbunatatirea-conformarii-cu-reglementarile-legale/ (accessed on 24.05.2025) [in Romanian].
36. Al Jawaldeh, A.; Al-Khamaiseh, M. Assessment of salt concentration in bread commonly consumed in the Eastern Mediterranean Region. *Eastern Mediterranean Health Journal* 2018, 24(1), pp. 18–24.
37. Mattes, R.D.; Donnelly, D. Relative contributions of dietary sodium sources. *Journal of the American College of Nutrition* 1991, 10(4), pp. 383–393.
38. Action on Salt, 2023. *The salt content of packaged pre-sliced bread*. London: Wolfson Institute of Population Health, Queen Mary University of London. Available online: https://www.actiononsalt.org.uk/media/action-on-salt/news/surveys/2023/Salt-Content-of-Packaged-Pre-Sliced-Bread_March23.pdf (accessed on 01.06.2025)
39. Dabija, A. Unconventional raw materials for the bakery industry. In: *Salt, a Benefic Ingredient in Bakery Products*? Performantica Publishing House, Iasi, Romania, 2020, pp. 173–200.
40. Soptica, F.; Zugravu, C.; Tarcea, M.P.D.; Pantea, S.A. Salt in fast food products and ready-to-eat sauces: Should it be a matter of concern for public health. *Bull. UASVM Agric*. 2012, 21, pp. 454–460.
41. Federation of Bakers. (2019). Salt in Bread: Factsheet No. 21. Available online: https://www.fob.uk.com/wp-content/uploads/2017/01/FS-21-Salt-in-Bread.pdf (accessed on 01.06.2025).
42. Lobo, C.; Ferreira, T. Hedonic thresholds and ideal sodium content reduction of bread loaves. *Food research international* 2021, 140, 110090.
43. Kuhar, A.; Korošec, M., Bolha, A., Pravst, I.; Hristov, H. Is a Consumer Perception of Salt Modification a Sensory or a Behavioural Phenomenon? Insights from a Bread Study. *Foods* 2020, 9(9), 1172.
44. Shen, D.; Song, H.; Zou, T.; Raze, A., Li, P.; Li, K.; Xiong, J. Reduction of sodium chlorine: A review. *Journal of the science of food and agriculture* 2022, 102(10), pp. 3931-3939.
45. Avramenko, N.; Tyler, R.; Scanlon, M., Hucl, P.; Nickerson, M. The chemistry of bread making: The role of salt to ensure optimal functionality of its constituents. *Food Reviews International*, 2016, 34(3), pp. 204 - 225.
46. Muresan, C.; Stan, L.; Man, S.; Scrob, S.; Muste, S. Sensory evaluation of bakery products and its role in determining consumer preferences. *Journal of Agroalimentary Processes and Technologies* 2012, 18(4), pp. 304-306.
47. Chen, G.; Ehmke, L.; Sharma, C.; Miller, R.; Faa, P.; Smith, G.; Li, Y. Physicochemical properties and gluten structures of hard wheat flour doughs as affected by salt. *Food chemistry* 2019 275, pp. 569-576.
48. Voinea, A.; Stroe, S.; Codină, G. The Effect of Sodium Reduction by Sea Salt and Dry Sourdough Addition on the Wheat Flour Dough Rheological Properties. *Foods* 2020, 9(5), 610.
49. Mironeasa, S.; Codină, G.G.; Mironeasa, C. Optimization of wheat-grape seed composite flour to improve alpha-amylase activity and dough rheological behavior. *Int. J. Food Prop*. 2016, 19, pp. 859–872.
50. Bordei, D. Modern technology of bread making. In: *Salt*. AGIR Publishing House, Bucharest, Romania, 2005, pp. 60–63.
51. Belz, M.C.E.; Ryan, L.A.M.; Arendt, E.K. The Impact of Salt Reduction in Bread: A Review. Crit. Rev. *Food Sci. Nutr*. 2012, 52, pp. 514–524.
52. Nahar, N.; Madzuki, I.N.; Izzah, N.B.; Karim, S.B.; Ghazali, H.M.; Karim, R. Bakery Science of Bread and the Effect of Salt Reduction on Quality: A Review. *BJRST* 2019, 1, pp. 9–14.
53. Moreau, L.; Lagrange, J.; Bindzus, W.; Hill, S. Influence of sodium chloride on colour, residual volatiles and acrylamide formation in model systems and breakfast cereals. *Int. J. Food Sci. Technol*. 2009, 44, pp. 2407–2416.
54. Codină, G.G.; Voica, D. The influence of different forms of bakery yeast Saccharomyces cerevisie type strain on the concentration of individual sugars and their utilization during fermentation. *Rom. Biotechnol. Lett.* 2010, 15, pp. 5417–5424.
55. Girgis, S.; Neal, B.; Prescott, J.; Prendergast, J.; Dumbrell, S.; Turner, C. A one-quarter reduction in the salt content of bread can be made without detection. *Eur. J. Clin. Nutr*. 2003, 57, pp. 616–620.

56. Doyle, M.E.; Glass, K.A. Sodium reduction and its effect on food safety, food quality, and human health. *Compr. Rev. Food Sci. Food Saf.* 2010, 9, pp. 44–56.
57. Pflaum, T.; Konitzer, K.; Hofmann, T.; Koehler, P. Analytical and sensory studies on the release of sodium from wheat bread crumb. *J. Agric. Food Chem.* 2013, 61, pp. 6485–6494.
58. Silow, C.; Axel, C.; Zannini, E.; Arendt, E.K. Current status of salt reduction in bread and bakery products—A review. *J. Cereal Sci.* 2016, 72, pp. 135–145
59. Dunteman, A.; Yang, Y.; McKenzie, E.; Lee, Y.; Lee, S.-Y. Sodium reduction technologies applied to bread products and their impact on sensory properties: a review. *International Journal of Food Science and Technology* 2021, 56(9), pp. 4396–4407.
60. Zolfaghari, M.; Seyedain Ardebili, S.M.; Asadi, G.H; Larijani, K. Evaluating the Effects of Sourdough, Bakery Yeast and Sodium Bicarbonate on Texture, Volatile Compounds and Staling of Barbari Bread. *Hacettepe Journal of Biology and Chemistry* 2015, 43(4), pp. 283–293.
61. Sun, X.; Scanlon, M.; Guillermic, R.; Belev, G.; Webb, M.; Arıtan, S.; Nickerson, M.; Koksel, F. The effects of sodium reduction on the gas phase of bread doughs using synchrotron X-ray microtomography. *Food Research International* 2020, 130, 108919.
62. Beck, M.; Jekle, M.; Becker, T. Impact of sodium chloride on wheat flour dough for yeast-leavened products. II. Baking quality parameters and their relationship. *Journal of the Science of Food and Agriculture*, 2012, 92(2), pp. 299-306.
63. McMahon, E.; Clarke, R.; Jaenke, R.; Brimblecombe, J**.** Detection of 12.5% and 25% Salt Reduction in Bread in a Remote Indigenous Australian Community. *Nutrients* 2016, 8**(**3), 169.
64. Bolhuis, D.; Temme, E.; Koeman, F.; Noort, M.; Kremer, S.; Janssen, A. A salt reduction of 50% in bread does not decrease bread consumption or increase sodium intake by the choice of sandwich fillings. *The Journal of Nutrition* 2011, 141(12), pp. 2249-2255.
65. Riis, N.; Bjoernsbo, K.; Toft, U.; Trolle, E.; Hyldig, G.; Hartley, I.; Keast, R.; Lassen, A. Impact of salt reduction interventions on salt taste sensitivity and liking, a cluster randomized controlled trial. *Food Quality and Preference* 2021, 87, 104059.
66. Wai, K.; Zhong, N.; Feng, Y.; Xu, Y. Salt Reduction: Product Challenges, Approaches, and Application of Flavors. In: *Flavor-Associated Applications in Health and Wellness Food Products*, Springer Cham, Switzerland, 2024, pp. 197–224.
67. Xu, X.; Zeng, L.; Jha, V.; Cobb, L.K.; Shibuya, K.; Appel, L.J.; Neal, B.; Schutte, A.E. Potassium-Enriched Salt Substitutes: A Review of Recommendations in Clinical Management Guidelines. *Hypertension* 2024, 81**,** pp. 400–414.
68. Ferrari, G. T.; Proserpio, C.; Stragliotto, L.; Boff, J.M.; Pagliarini, E.; Oliveira, V.R. Salt reduction in bakery products: A critical review on the worldwide scenario, its impacts and different strategies. *Trends in Food Science and Technology* 2022, 129(6), pp. 440-448.
69. Rysová, J.; Šmídová, Z. Effect of Salt Content Reduction on Food Processing Technology. *Foods* 2021, 10**(**9), 2237.
70. Mamyrayev, M.; Iztayev, A.; Kulazhanov, T.; Yakiyayeva, M.; Yerzhanova, M.; Askarbekov, E.; Muldabekova, B.; Maliktayeva, P.; Tursunbayeva, S. Innovative Methods for Reducing Sodium in Cupcakes with Mechanical Leavening and Ozonized Water. *International Journal of Food Science* 2024, 706504.
71. Chen, G.; Hu, R.; Li, Y. Potassium chloride affects gluten microstructures and dough characteristics similarly as sodium chloride. *Journal of Cereal Science* 2018, 82, pp. 155-163.
72. Strohm, D.; Ellinger, S.; Leschik-Bonnet, E.; Maretzke, F.; Heseker, H. Revised Reference Values for Potassium Intake. *Annals of Nutrition and Metabolism* 2017, 71, pp. 118 - 124.
73. Turck, D.; Bresson, J.-L.; Burlingame, B.; Dean, T.; Fairweather-Tait, S.; Heinonen, M.; Hirsch-Ernst, K.I.; Mangelsdorf, I.; McArdle, H.; Neuhäuser-Berthold, M.; Nowicka, G.; Pentieva, K.; Sanz, Y.; Siani, A.; Sjödin, A.; Stern, M.; Tomé, D.; Van Loveren, H.; Vinceti, M.; Willatts, P.; Aggett, P.; Martin, A.; Przyrembel, H.; Brönstrup, A.; Ciok, J.; Gomez Ruiz, J.A.; de Sesmaisons-Lecarre, A.; Naska, A. Dietary reference values for potassium. *EFSA Journal* 2016, 14(10), e04592.
74. Woodruff, R.; Zhao, L.; Ahuja, J.; Gillespie, C.; Goldman, J.; Harris, D.; Jackson, S.; Moshfegh, A.; Rhodes, D.; Sebastian, R.; Terry, A.; Cogswell, M. Top Food Category Contributors to Sodium and Potassium Intake - United States, 2015–2016. *Morbility and Mortality Weekly Report* 2020, 69, pp. 1064 - 1069.
75. Cepanec, K.; Vugrinec, S.; Cvetković, T.; Ranilović, J. Potassium Chloride-Based Salt Substitutes: A Critical Review with a Focus on the Patent Literature. *Comprehensive Reviews in Food Science and Food Safety* 2017, 16(5), pp. 881-894.

76. Antúnez, L.; Giménez, A.; Vidal, L.; Ares, G. Partial replacement of NaCl with KCl in bread: Effect on sensory characteristics and consumer perception. *Journal of Sensory Studies* 2018, e12441.
77. Reißner, A.M.; Wendt, J.; Zahn, S.; Rohm, H. Sodium-chloride reduction by substitution with potassium, calcium and magnesium salts in wheat bread. *LWT - Food Science and Technology* 2019*,* 101, pp. 153−159
78. Marco, E.; Navarro, J.; León, A.; Steffolani, M. Sodium chloride replacement by potassium chloride in bread: Determination of sensorial potassium threshold and effect on dough properties and breadmaking quality. International *Journal of Gastronomy and Food Science* 2022, 27, 100486.
79. Hu, Y.; Wang, Q.; Sun, F.; Chen, Q.; Xia, X.; Liu, Q.; Kong, B. Role of partial replacement of NaCl by KCl combined with other components on structure and gel properties of porcine myofibrillar protein. *Meat science* 2022, 190, 108832.
80. Araújo, C.; Sant'Anna, L.; Da Silva Moreira, E.; De Paula, M.; Della Lucia, S.; De Carvalho, R.; Saraiva, S.; Lima, R.; Filho, L. How much can sodium chloride be substituted for potassium chloride without affecting the sensory acceptance of cracker-type biscuits? *Food research international* 2021, 150 Pt A, 110798.
81. Charlton, E.; MacGregor, E.; Vorster, N.; Levitt, N.; Steyn, K. Partial replacement of NaCl can be achieved with potassium, magnesium and calcium salts in brown bread. *International Journal of Food Sciences and Nutrition* 2007, 58, pp. 508-521.
82. Hernández-Figueroa, R.; Mani-López, E.; Palou, E.; López-Malo, A. Sourdoughs as Natural Enhancers of Bread Quality and Shelf Life: A Review. *Fermentation* 2024, 10(1), 7.
83. Belz, M.; Axel, C.; Arendt, E.; Lynch, K.; Brosnan, B.; Sheehan, E.; Coffey, A.; Zannini, E. Improvement of taste and shelf life of yeasted low-salt bread containing functional sourdoughs using *Lactobacillus amylovorus* DSM 19280 and Weisella cibaria MG1. *International Journal of Food Microbiology* 2019, 302.
84. Arendt, E.; Ryan, L.; Bello, D. Impact of sourdough on the texture of bread. *Food microbiology* 2007, 24(2), pp. 165-174.
85. Torrieri, E.; Pepe, O.; Ventorino, V.; Masi, P.; Cavella, S. Effect of sourdough at different concentrations on quality and shelf life of bread. Lwt - *Food Science and Technology* 2014, 56, pp. 508-516.
86. McCutcheon, N.B. Salt-acid confusion on the single fungiform papilla: effect of changing acid sensitivity. *Physiology and Behavior* 1986, 36, pp.1081−1088.
87. Kilcast, D. Salt: The flavour enhancer. In: *Reducing salt in foods: Practical strategies*. Kilcast, D.; Angus, F. (eds.). Woodhead Publishing, Cambridge, UK, 2007, pp. 366−395.
88. Preston, K.R. Effects of neutral salts upon wheat gluten protein properties. *Cereal Chemistry* 1981, 58(4), pp. 317−324.
89. Golshan Tafti, A.; Peighambardoust, S.H.; Behnam, F.; Bahrami, A.; Aghagholizadeh, R.; Ghamari, M.; Rafat, S.A. Effects of spray-dried sourdough on flour characteristics and rheological properties of dough. *Czech Journal of Food Sciences* 2013, 31(4), pp. 361−367.
90. Nogueira, A.; Kussano, J.; Steel, C. Sourdough reduces sodium in wheat flour doughs. *International Journal of Food Science and Technology* 2015, 50(12), pp. 2621-2629.
91. Lopez-Moreno, C.; Fernández-Palacios, S.; Márquez, P.; Márquez, S.; Montosa, C.; Otero, J.; Navarrete, J.; Ortiz, R.; Delgado, M. Assessment of Acrylamide Levels and Evaluation of Physical Attributes in Bread Made with Sourdough and Prolonged Fermentation. *Food Science and Engineering* 2023, 5(1), pp. 34-48.
92. Belc, N.; Smeu, I.; Macri, A.; Vallauri, D.; Flynn, K. Reformulating foods to meet current scientific knowledge about salt, sugar and fats. *Trends Food Sci Tehnol*. 2019, 84, pp. 25−28.
93. Jimenez-Maroto, L.; Sato, T.; Rankin, S. Saltiness potentiation in white bread by substituting sodium chloride with a fermented soy ingredient. *Journal of Cereal Science* 2013, 58, pp. 313-317.
94. Sadowska-Rociek, A. The effects of adding "flavour enhancers" on levels of chloropropanediol esters and glycidyl esters in savoury shortbread. *European Food Research and Technology* 2018, 245, pp. 489-498.
95. Rocha, R.; Ribeiro, M.; Silva, G.; Rocha, L.; Pinheiro, A.; Nunes, C.; Carneiro, J. Temporal profile of flavor enhancers MAG, MSG, GMP, and IMP, and their ability to enhance salty taste, in different reductions of sodium chloride. *Journal of Food Science* 2020, 85(5), pp. 1565-1575.

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