Salt reduction in bakery products: A critical review on the worldwide scenario, its impacts and different strategies

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1.Introduction

Sodium chloride is an essential component in the preparation of food formulations. In baking processes, it confers physico-chemical properties and contributes to defining the sensory attributes of the product, being one of the main ingredients of the formulation. However, the scientific literature has established a concerning relationship between the excessive sodium consumption and the increased blood pressure, a risk factor for cardiovascular disease and all-cause mortality (He, 2021), calling the attention of the scientific community to have initiatives to reduce sodium ingestion.

In 2017, about 17.8 million people died from cardiovascular diseases, making it the leading cause of death worldwide. It is estimated that 2.5 million of these deaths could be prevented if sodium intake was reduced to the level recommended by the World Health Organization (less than 2 g/day), making the high sodium content in the diet of populations a public health problem. Therefore, the World Health Organization member states set a goal in 2012 to reduce sodium intake by 30% by 2025 (WHO, 2012).

Considering that about 70% of the sodium consumed is added to the food before it reaches the hands of the consumer (Mello, 2019), sodium reduction initiatives should be applied as early as the industrial production phase of the food. Reducing sodium consumption is a double pathway: while consumers need to be aware of the harmful effects of excess sodium, food manufacturers need to collaborate to provide healthier food products available for consumers.

Bakery products are one of the major contributors to sodium consumption all over the world, salt reduction initiatives must involve this food category. Since salt plays numerous roles on the techno-functional and sensory properties of those products, different strategies must be studied to evaluate the best way to reduce salt without compromising product quality and consumer acceptance.

This paper aims to investigate the current worldwide overview regarding sodium reduction in bakery products, to evaluate different strategies, as well as their technological and sensory impacts on these products, besides discussing relevant aspects of sodium reduction.

2. Sodium chloride: sources, functions and intake recommendations

Sodium chloride (NaCl), also known as salt, is composed of sodium and chlorine ions and accounts for about 90% of sodium ingestions worldwide (Minegishi et al., 2020).

The Dietary Reference Intakes have not established RDA (Recommended Dietary Allowance) or EAR (Estimated Average Requirement) values for sodium, since cases of sodium deficiency are rare and adequate sodium intake is achieved "under a wide variety of conditions, including low sodium intake and extreme heat" (National Academies of Sciences, Engineering and Medicine, 2019).

The adequate intake (AI) amount for U.S. adults of both genders has been established at 1.5g/day, equivalent to approximately 3.7 g of sodium chloride (McGuire, 2014). Globally, the World Health Organization has set a recommendation of 5g of salt/ day, approximately 2g of sodium.

3. Sodium consumption and bakery products

High-sodium foods - such as ultra-processed foods - are increasingly available in the global food system, as they are cheap, hyperpalatable, and highly available in supermarkets (Lane et al., 2021).

In developed western countries, salt added in processed foods and restaurants are the major sources of sodium intake, contributing to about 70-75% of sodium intake. The remaining sodium comes from salt added in cooking and from natural source foods. This pattern applies to urban regions, whereas in rural areas and in developing countries salt added in cooking also contributes significantly to sodium intake, potentially exceeding 50% of total sodium intake (Perin et al., 2019).

Bhat et al. (2020), observed that bakery products are the main source of sodium in several European countries, in the USA and in South Africa, ranging from 25 to 40% of total sodium intake. In South America, bread is also a significant source of sodium, but on a smaller scale, ranging from 15 to 30% in Brazil, Argentina and Colombia.

The contribution of bakery products to excessive sodium intake is due to its large-scale consumption. Even if bread has reduced sodium levels compared to, for example, instant noodles or ready-made sauces, it is still an important factor in excessive sodium intake, since breads are consumed in large amounts (Table 1).

TABLE 1

Among the sodium reduction policies in the food industry, voluntary agreements are observed to a greater extent because they are more easily implemented. However, they require enforcement and depend on industry commitment. In a review study involving 75 countries, only nine of them included mandatory sodium reduction policies for the industry, with bread included in seven of those policies (Webster, 2014). This is observed because, in some countries, implementing a new legislation is time-consuming, is taking considerable effort to be implemented.

In Italy, bakery products took a central role in sodium reduction strategies as bread is a major source of non-discretionary salt for the Italian population, according to the Italian Institute of Nutrition (Turrini et al., 2001). Sodium reduction strategies started with voluntary agreements between the Italian Ministry of Health and associations of artisan bakers and the food industry, later evolving to the National Prevention Plan 2014-2019, which was renewed for 2020-2025. As a result, a relative reduction of 10-15% of the salt content was achieved (Donfrancesco et al., 2021).

An interesting example of success of reduction is the United Kingdom: within a decade, the sodium content in breads was reduced without compromising the sensory aspects of the products and resulted in a lower sodium intake by the British population (He, 2014). However, a change in the agencies regulating sodium reduction policies from 2011 to 2017 marked a loss of progress (He, 2019).

In South America, Argentinian government implemented Act 26.905, which established a maximum sodium level for farinaceous, meat products, soups and sauces. In a sample of white bread analyzed (n=32), 15.6% had not complied with the sodium limit set by Act 26.905 (501 mg/100 g) (Allemandi, 2019).

In Brazil, sodium reduction programs began in 2010, with National Sodium Reduction Plan implemented by the national Ministry of Health. In this program, the food production sector was mobilized for voluntary reformulations in processed and ultra-processed foods. The method chosen was the silent approach, focusing on gradual changes in formulations. In reducing sodium chloride amount and with targets updated every two years. For this, primary food categories were selected according to their contribution to excessive sodium intake. Several types of breads were included, such as 'sandwich loaf' and 'batard bread' (a type of long loaf with low crust to crumb ratio) (Brazil, 2018). Nilson et al. (2017) analyzed the first seven years of the National Sodium Reduction Plan and observed that all bread samples analyzed (n=94) had reached the target set by the Pan American Health Organization (600 mg of sodium for 100 g of bread) between 2011 and 2014. The study considered only data from the Brazilian Food Industry Association, which does not include all types of breads and bakery products consumed in Brazil.

Table 2 summarizes different bakery products and their respective sodium content. It can be observed that, even after sodium reduction initiatives, some products still have a significant quantity of sodium, as is the case of cheese bread in Brazil. Besides this, sweet products like cookies and puff pastry also have a considerable amount of sodium even though they are not considered salty products.

TABLE 2

4. Technological impact of sodium chloride in breads and other bakery products

Sodium chloride is in the formulation of most bakery products and is considered one of the four essential ingredients in breads, along with flour, water and yeast (Miller & Hoseney, 2008).

In wheat breads, sodium chloride stabilizes the gluten, decreasing the extensibility of the dough and making it less viscous, which mitigates production losses. In addition, NaCl inhibits yeast fermentation, reducing the release of gas (Figure 1). At lower amounts of sodium chloride, the fermentation rate is increased, enlarging the alveoli disproportionately and impairing product texture. Also, sodium has a hygroscopic property, which decreases the water activity of the bread, making the environment less prone to microbiological activity and increasing the shelf life of the product (Cauvain & Clack, 2019).

Rheological analyses are important to understand the processes that occur during the dough formation, since the wheat bread dough has several viscoelastic properties attributed by gluten (Cappelli et al., 2020). The viscoelastic behavior of gluten in bakery products is due to its proteins: gliadin which is responsible for viscosity, and glutenin responsible for elasticity (Wang et al., 2020).

The technological impact of sodium chloride can be observed in breads and other leavened products, as well as laminated products such as croissants and puff pastry (Silow et al., 2016). The scientific literature about the role of sodium in cakes, cookies, biscuits and confectionery products is still scarce, even though these products may contain significant amounts of sodium (Ayed et al., 2021).

FIGURE 1

In the process of kneading or rolling, the extensibility of the dough is a factor that can predict the final quality of the products (Silow et al., 2016). Lynch et al. (2009) evaluated the extensibility of doughs with 0; 0.3; 0.6; 1.2% of NaCl with a strain gauge. The results showed that the dough strength (Rmax) and extensibility (E') had no significant differences between the doughs with 0.3 and 1.2% of NaCl. However, the dough with 0% sodium chloride showed significant differences ($p<0.05$) compared to the 1.2% formulation, with a 21% and 26% reduction in dough strength and extensibility, respectively, which shows that the total absence of sodium chloride in the formulations can impact dough extensibility.

Previous results depicted that the addition of NaCl reduces dough stickiness as it optimizes water absorption in the dough system (Diler et al., 2016). However, Beck et al. (2012) found a decrease in dough stickiness, according to NaCl concentration decrease (40-0 g/kg flour). The authors mentioned that these contradictory results can be explained by the polarity of gluten, since they have positively charged amino acids, gluten proteins tend to repulsion. When NaCl at low concentrations is added to the dough, the repulsion of the gluten proteins is neutralized, bringing the molecules closer together and favoring the formation of gluten chains. Thus, gluten is not as hydrated when NaCl is present.

Sodium chloride stabilizes the crumb, making it more uniform. Lynch et al. (2009) observed that bread samples without added sodium chloride had larger and less uniform alveoli when compared to samples with 0.3-1.2% sodium chloride. On the other hand, this same study showed that bread hardness was independent of the amount of NaCl, remaining similar in all formulations with NaCl after storage for 2-50 hours. The only formulation with unacceptable firmness after 120 hours of storage was the one with 0% NaCl.

NaCl levels can cause excessive fermentation, thus the fermentation time should be adjusted from any change in NaCl concentration. This reduction in NaCl that increases the fermentation rate of the dough, may also reduce sugar availability for Maillard reaction. Thus, sodium-reduced breads have fewer volatile compounds and have a lighter colored crust (Pasqualone et al., 2019), results similar to that were found by Raffo et al. (2018).

Lynch et al. (2009), observed that reducing NaCl from 1.2% to 0.6% and 0.3% significantly decreased the CO_2 retention coefficient (RC). The maximum loaf height increases as the NaCl level decreases.

On sweet biscuits, salt reduction decreases water activity and affect the texture of the product According to Ayed et al. (2021). Biscuits without added salt were fragile and easier to break. This texture change could be explained by the microstructure of the salt reduced biscuits, which showed larger cells, with more air. Furthermore, salt reduction did not impact the color and volatile compounds of biscuits.

Since bakery products have high levels of water activity (88 to 95% for breads and 70 to 88% for cakes), calculated from the balance of relative humidity, the water activity of the bakery products is very high (95% for breads and 70 to 88% for cakes, respectively), consequently these foods are considered vulnerable to microbiological activity (Cauvain & Clark, 2019).

In another study with substitutes for cooking salt (potassium, calcium and magnesium salts), the authors observed that there was no significant difference in water activity among the breads. Therefore, the authors inferred that the shelf life was not affected by the substitution with these other types of salts (Reißner, 2019).

5. Impacts of sodium reduction on sensory quality of bakery products

The sodium concentration in bakery products is important in defining sensory acceptance since texture, flavor, odor and color can be modified according to salt addition. Thus, at industrial scale, sodium reduction in bakery products without negatively affecting sensory quality is still a major challenge (Dunteman et al., 2021). Salt concentration in bakery products could directly affect crust color, as well as odor and flavor attributes, due melanoidins production of the final stage of the Maillard Reaction. Bread baked without salt had lighter colored crust due to the reduced amounts of free sugars. Indeed, in samples with low salt the yeast is more active and therefore metabolizes much more sugar, reducing crust coloring during baking (Soliw et al., 2016).

The extent to which salt reduction influences the flavor of baked products is also due to the ingredients used for food production. It has been suggested that it could be possible to reduce by 25% salt content in bread without detection or even up to 50%, while other findings showed a significant effect on flavor perception – leading to "yeasty," "sour," or "acidic" and having "sourdough" sensory characteristics – with the latter reduction (Lynch et al., 2009).

Besides changes in color, odor and flavor perception, salt has an important impact on texture dimension of the bakery products due to its role in the development of the gluten network and the crumb structure (Israr et al., 2016). Bread without salt has been widely described as uniform but with a 'heavily walled' crumb grain, mainly due to a smaller number of larger air cells when compared to bread containing salt (Lynch et al., 2009).

Several studies, especially on bread samples, have been performed to evaluate to what extent it could be possible to reduce salt concentration without compromising product acceptability. Some authors depicted a feasibility in reducing the sodium content up to 50% without decreasing sensory acceptability of the product (Pasqualone et al., 2019) and other findings reporting negative effect of reducing salt amount on liking ratings (Antunez et al., 2016).

Recent data obtained with wheat durum bread with an increased concentration of salt (5, 10, 15 and 20% by flour weight) revealed that bread with the lowest salt amount was rejected by the consumers, whereas products with 15% and 20% were the preferred ones. Bread with 10% of salt was described to have a less consistent crumb, a less intense crust color, a stronger yeasty odor, a weaker toasted odor, a lower salty taste score and higher sweet taste scores compared to bread with the highest salt concentration (Pasqualone et al., 2019).

Other recent findings depicted that hedonic assessment of white bread was not influenced by salt concentration (15% less or 10% more salt compared to the control), whereas hedonic assessment of multigrain bread was affected significantly by salt amount with sample with the lowest concentration liked less than the control (Kuhar et al., 2020). It should be considered that sensory perception greatly differs among individuals directly affecting the food choice and subsequent food consumption (Proserpio et al., 2018). The individual variation in taste perception has been largely investigated as responsiveness to the bitter compound 6-n-propylthiouracil (PROP) and more recently, a general taste responsiveness score was proposed to identify subject groups differing for responsiveness to basic tastes (Puputti et al., 2018).

There is an individual threshold of salt sensitivity, which shows the amount of sodium needed to activate channels in the epithelium of the sensory receptors. The activation of these sensory receptors results in an afferent electrical impulse to the brain. The amount of sodium required to recognize the salty taste can vary individually. Thus, a food sample that could be perceived as saltless by some consumers could be perceived differently by others.

Kuhar et al. (2020) found segments of consumers that respond differently according to salt concentration in bread, with consumers ‘salt indifferent’, other not perceiving enough salt in any products (‘salt adherent’) and another group of consumers perceiving all the samples as having too much salt (‘salt sensitive’). The ‘salt adherent’ group was aware of their excessive salt consumption but was significantly less careful about limiting it. These data confirm that for some consumers prevails more what they perceive with their senses and the pleasure deriving even if they are aware about the need to reduce the daily salt consumption to maintain and preserve a good state of health.

It should be argued that human senses could be ‘guide’ and our eating behavior can change through the daily life experience. For example, a reduction in the amount of sugar in coffee could be achieved with a gradual, daily reduction of the sugar added leading the senses to detect lower concentrations of the taste stimulus and be gradually satisfied by the lower sugar concentrations.

This strategy could also be applied in reduction of salt intake. Accordingly, it has been recently revealed that at baseline, bread with low salt (0.4 g / kg) was less liked compared to samples with higher salt concentrations (0.8 and 1.2 g / kg), whereas at follow-up after four months there was a reduction in liking of the bread with highest salt amount. Although salty taste thresholds at follow-up were not affected by the gradual reduction of salt content, subjects who received dietary counseling had significantly lower detection thresholds and liked more bread with the lowest salt amount, while those without dietary counseling had not (Riis et al., 2021). While this reduction in liking of the highest salt bread may indicate a change in salt preference over time, these data depict also the importance of dietary counseling and nutritional education on food choice.

Recently, some authors investigated how and to what extent information about 'sodium warning' could affect white bread samples liking ratings (Antúnez et al., 2020), and they found that regardless of their salt preference, the presence of a 'sodium warning' was found to encourage consumers to shift consumer preference towards lower sodium breads. However, the information provided to the consumers is not always enough to lead them to accept and consume new food products. Indeed, consumers often establish behaviors and habits in contrast with their beliefs, intentions and opinions. Moreover, it should be argued that recent literature suggests that consumers are unaware about the impact of baked product consumption on total sodium intake (Dunteman et al., 2021), revealing the need for education about sodium sources to raise consumer awareness.

Education should start at an early stage of life since it is widely reported that some habits acquired in childhood as well as the nutritional status could persist into later life (Scaglioni et al., 2018). Some results revealed that children did not perceive differences in the saltiness intensity between either bread formulation (white and French breads) or salt level (1.2 and 1.8 g kg -1 flour). As a whole, the salt-reduced breads were well-accepted by children. These results are promising in order to reach the goal to reduce salt diet consumption already at an early stage of life.

6. Initiatives to reduce sodium around the world

Literature data about strategies to reduce sodium have grown in recent years, going from a gradual stealth reduction to the incorporation of new components to the formulation, such as salt replacers and sourdough. The main sodium reduction strategies are summarized in Figure 2.

FIGURE 2

6.1 Gradual reduction

Bakery products reformulation by gradual and silent reduction of NaCl concentration is considered one of the simplest and widely applied strategies by food industries (Nilson, 2020). It is considered effective since the preference for salt taste is not immutable, but is conditioned by perceptive, environmental and behavioral factors (Riis et al., 2021). This strategy can be applied over months or years, and once the consumer's palate has adapted to the lower sodium formulation, a new reduction target can be set.

The gradual and silent reduction strategy was successfully used in the United Kingdom between 2000 and 2011. Government officials set specific targets for each food category, monitoring the results and setting new targets every 2-3 years. The agreements with industry were voluntary, but there was the threat of binding legislation if targets legislation were not met. The results were seen in the average sodium intake of the population: in 11 years, sodium intake decreased by 15% (He, 2014).

In a pilot experiment with 22 voluntary bakeries in Bizerte, Tunisia, a salt reduction of 35% was achieved without detection by Tunisian consumers. The salt reduction was gradually applied over the course of three months with 184 consumers and the NaCl concentration in bread was reduced to 1.1 g/100 g without detection by Tunisian customers. After the three-month period of saltiness perception assessment, the 22 bakeries were able to maintain these salt levels for 2 years and 9 months (El Ati et al., 2021).

A limitation of this approach is its critical threshold, when the products' technological and sensory properties are compromised, no longer being accepted by the consumer, since a 40% reduction in salt was detected by most of the participants (El Ati et al., 2021). Therefore, the critical threshold for salt reduction in this study was 35%. In addition, it is important that the entire food industry in the same category is aligned in the sodium reduction targets. If a brand of sliced bread, for example, reduces the NaCl content while another brand continues to sell high-sodium, it may be more difficult for consumers' taste buds to adapt (Zandstra et al., 2016). This was evidenced in a cluster randomized controlled trial published in 2021, in which the researchers found that consuming bread with high salt content modulates taste sensitivity, decreasing acceptance of salt reduced bread (Riis et al., 2021).

Reductions of NaCl to 0.3 - 0.6% are possible without impairing the rheological properties of the bakery product, but not without compromising the sensory properties (Lynch et al., 2009). Critical reductions of sodium chloride in bakery products should be combined with the addition of other compounds, that will be discussed below, such as potassium chloride and other salts, sourdough salts, sourdough, herbs and spices.

In table 3 are reported the main studies approached in this review with their respective feasible reduction.

TABLE 3

6.2. Salt replacers

Among the salts used to replace sodium chloride, potassium chloride (KCl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$) and magnesium sulfate ($MgSO_4$) are the best documented in this review. These anions can be used alone or in combination with each other (Reißner et al., 2019).

Reißner et al. (2019) observed that 50% replacement of NaCl with KCl did not impair the technological properties of the dough and sensory aspects of the bread, leaving the final product similar to the standard (with only NaCl). Furthermore, the study also assessed the effect of calcium and magnesium salts. The application of magnesium chloride in small amounts (0.15 g/ 100 g of flour) did not impair the properties of the bread and could be a good alternative to increase the flavor. The addition of calcium ($CaCl_2$) to the formulation weakened the protein structure of the dough, resulting in loaves with larger volume and softer crust and crumb. In other words: divalent cations had an impact on dough and bread when compared to monovalent ones.

In a study with wheat bread and commercial salt (NaCl 57%, KCl 28%, $MgSO_4$ 12%, lysine hydrochloride 2%, silica 1%, iodine 0.0036%) at concentrations of 1.5% and 3%, it was partially able to maintain the salty taste. Furthermore, the addition of 3% increased the bitterness and bitter taste and the aftertaste of the bread crust (Raffo et al., 2018).

Another strategy seen in the literature is the substitution of sodium chloride by commercial seawater, which is rich in many other minerals such as calcium, potassium, magnesium, selenium and iodine. Iaccarino Idelson et al. (2020) evaluated two different recipes of Neapolitan pizza, one with tap water and sodium chloride and the other one only with commercial seawater. It was found that seawater pizza had 50% less sodium. The reduction of sodium by half impacted the saltiness perception by the sensory panel, as seawater pizza scored significantly lower for saltiness. Despite that, general pleasantness for both pizzas showed no significant differences. The study also assessed sodium metabolism in the postprandial period, finding that the consumption of seawater pizza led to higher urine volume and larger proportion of ingested sodium excretion in the urine. Seawater was previously used in a study with wheat bread, with promising results such as lower sodium content and increased micronutrients content (Barbarisi et al., 2019).

Taste enhancers can be a useful tool to increase flavor perception of baked goods with reduced salt, even if they do not have a salty taste themselves. Some taste enhancers are chemical substances, such as monosodium glutamate (MSG) and hydrolyzed protein (Israr et al., 2016). Since the use of monosodium glutamate is controversial for its potential toxicity (Nahok et al., 2021) and more studies are needed to elucidate its effects on the human organism, this review will focus on clean label alternatives.

Much attention has been given to hydrolysates protein, which are a blend of oligopeptides, peptides and free amino acids that are released from protein molecules by partial or extensive hydrolysis through chemical cleavage using acid or alkali, proteolytic bacteria, or proteolytic enzymes (Nasri, 2017). Currently, more than 50 umami peptides from different sources, such as: soybean, peanut, fish, beef, have been identified (Zhang et al., 2017).

For Cepanec et al. (2017), salt substitutes characterized by umami ingredients is based on yeast and hydrolyzed protein which can include hydrolyzed animal and vegetable proteins. While hydrolyzed animal and vegetable proteins usually contain only glutamate and aspartic acid as umami substances, various yeast-based raw materials and yeast can be considered natural sources of glutamate and/or 5'-ribonucleotides. Several yeast-based ingredients in KCl -based salt substitute formulations provide advantageous effects, such as: taste-enhancing properties through the contribution of umami taste elimination or reduction of bitterness and metallic taste of KCl; improved perception of salty taste.

Incorporation of KCl has also been mentioned affecting rheological/textural and sensory quality of wheat bread. Since KCl can influence the hydration of gluten protein and consequently stickiness, extensibility, viscoelastic, besides sensory attributes of dough and bread (Pashaei et al., 2021).

Reducing salt is a chemical, technological and sensory challenge in bakery products, because its effect is not only on product sensory attributes perception, but it also plays a functional role in bakery products in fermentation, dough stability and bread height. Synergistic effect can be suggested as well, for example the substitution levels can affect the taste of the bread, influence the color, resulting in a darker crust and crumb bread in a substitution level of 10-50% of salt (Jimenez-Maroto et al., 2013).

6.3. Taste enhancers: herbs and spices

Considering the rising consumer awareness about the ingredient list, other more common options have also been considered and further studied such as: herbs and spices (H&S) which can be a viable option to enhance flavor of salt reduced products as it would go towards the recent demand for clean label products (Driscoll et al., 2019).

Many studies have shown the effectiveness of herbs and spices on increasing saltiness of sodium-reduced foods or masking the bitter aftertaste of alternative salts such as potassium chloride. H&S were a sensory acceptable addition to foods like legume based dishes (Vannereux et al., 2020), beef hamburger (Carvalho et al., 2017), soups (Wang et al., 2014) and bologna sausage (Carraro et al., 2012), but H&S enriched product had similar acceptance in relation to the control product.

Kohri et al. (2020) assessed the potential effect of basil, rosemary, parsley, anise and oregano on the enhancement of saltiness perception in a saline solution. After sensory evaluation with 69 students, it was estimated that the addition of 0.35% herb extracts enhanced saltiness perception in 1.22%. No significant differences were observed among saltiness-enhancement properties of five different herbs that were analyzed.

Even though bread is a staple food, research on the effect of H&S on low-salt bread remains scarce. In a study with no-salt wheat bread enriched with thyme, lemon balm and nettle, two different methods were followed: single-phase method with addition of dry herbs and a method based on scalded flour, which used herbal infusion. Single-phase method led to lower bread volume, decreased brightness and redness of crumb and increased total phenolic content and antioxidant activity. The scalded flour method leads to a better quality no-salt bread, with lower crumb hardness and chewiness when compared to the single-phase bread (Wójcik et al., 2021a). It also implicates changes in manufacturing process, which would be considered a challenge for the manufacturers.

Dziki et al. (2021) studied the potential effect of sumac flour (*Rhus coriaria* L.) as a taste enhancer on wheat bread. Sumac is a small Mediterranean tree and its fruits have various applications such as spices, natural preservatives, management of blood lipids in diabetic patients, among others. Technologically, addition of sumac flour led to weakened gluten, resulting in decreased water absorption, lower stability of dough and increased development time of dough. As a result, sumac flour in a concentration higher than 2 g/100 g of wheat flour had decreased bread volume and increased crumb hardness. Furthermore, the addition of sumac flour increased redness of crumb and decreased lightness and yellowness. After sensory evaluation, it was found that the amount of 1 - 2 g of sumac flour was accepted by the panelists, indicating that sumac flour is a more effective taste enhancer when used in lower levels.

6.4. Taste contrast: heterogeneous salt distribution and encapsulated salt

Taste contrast in bakery products is another strategy being studied to increase consumer perception of salty taste without the addition of alternative salts or flavor enhancers. The two main methods of taste contrast are the heterogeneous salt distribution of NaCl and the use of encapsulated salt and they will be deeply discussed below.

Noort et al. (2010) have shown that the contrast of NaCl concentrations in the same bakery product increases the intensity of the salty taste, even if the total NaCl concentration has been reduced. In samples of 'sandwich bread', the authors observed that the heterogeneous distribution of sodium chloride allowed a reduction of up to 28% without compromising the salty taste and without the use of flavor enhancers or salt substitutes. In this case, heterogeneous distribution was achieved by combination of layers of dough with different NaCl concentrations.

In a comparative study between heterogeneous NaCl distribution and the use of commercial alternative salt (Sinesio, 2019), the wheat bread sample with heterogeneous distribution showed a salty taste similar to that of the control formulation (1.5% NaCl), demonstrating the effectiveness of the strategy. The use of alternative salt (NaCl, KCl, MgSO4 and a patented salt) showed better acceptability by the assessors (58%), than the bread with heterogeneous distribution, which was accepted by 31% of assessors.

In a study with salt agglomerates produced by waxy starch as a strategy for inhomogeneous distribution (Monteiro et al., 2021), the physicochemical properties, such as specific volume, texture profile and color, showed no significant alterations. Furthermore, a 30% NaCl reduction was achieved with no saltiness perception difference, indicating that the use of salt agglomerates does not affect these quality parameters.

Konitzer et al. (2013) analyzed the impact of applying granulated sodium chloride in wheat bread on chewing processes. The use of granulated salt accelerated the clearance of sodium to sensory receptors in the mouth, increasing the perception of salty taste even with a 25% reduction in NaCl. This strategy also worked in a study with pizza, enabling a 25% reduction (Mueller, 2016).

Another technological approach to reduce sodium content in bread is the use of encapsulated salt. In this strategy, the encapsulated salt is heterogeneously distributed in the dough, resulting in “salty spots”. In wheat bread, Noort et al. (2012) used crystals of encapsulated salt in high melting fat with the medium particle size of 500 μm. A reduction of 50% was achieved without losing saltiness intensity. It was found that the particle size of the encapsulates affect the perception of saltiness. Small encapsulates result in small concentration gradients of salt, while large encapsulates lead to more expressive concentration gradients of salt, increasing saltiness intensity and negatively impacting in sensory acceptance.

The combination of layers of dough with different concentrations of NaCl, the use of encapsulated salt, salt agglomerates and granulated sodium chloride has little impact in the industry as it does not imply drastic changes in the industrial process.

6.5. Sourdough

Sourdough is a traditional biotechnology that has been used for thousands of years for fermentation of baked products. As sourdough has many impacts on the technological and sensory characteristics of baked products, studies on this strategy have been growing since the 1990s (Gobbetti et al., 2019). Sourdough improves the flavor of low-salt bread and shows antihypertensive compounds (Peñas et al., 2015).

Belz et al. (2019) observed in wheat bread, two different lactic acid bacteria strains: *W. cibaria* MG1 (exopolysaccharide producing strain) and *L. amylovorus* DSM 19280 (antifungal strain), were used. After rheological and sensory analyses, the results depicted that the addition of sourdough on salt bread significantly increased the product quality. The optimum addition level of *W. cibaria* was 18%, increasing bread volume, crumb porosity and shelf life. Sourdough with a mixture of *L. amylovorus* DSM 19280 and *W. cibaria* MG1 lead to breads with softer bread crumbs, prolonged shelf life, increased bread volume and good sensory acceptance. On puff pastry, sourdough enables a salt reduction of 30% when used in a concentration of 10%/flour weight (Silow et al., 2016).

Rheological analysis conducted by Voinea et al. (2020) revealed that addition of dry sourdough in salt reduced wheat dough resulted in weakening during mixing and extension. Also, addition of dry sourdough provoked higher resistance to extension (R50) and maximum resistance to extension (Rmax), when compared to wheat dough added with sea salt. Furthermore, the sourdough dough had a decreased peak of viscosity.

The antihypertensive potential of sourdough comes from Lactobacilli, which can convert glutamate into γ-amino butyric acid (GABA). Peñas et al. (2015) demonstrated that addition of whole meal wheat sourdough (produced by L*actobacillus brevis* CECT 8183 and protease) on wheat bread made GABA contents 7 times higher than control bread.

Furthermore, sourdough can be a useful strategy for salt reduction as it is a natural preservative, compensating the absence of salt as a food preservative. Belz et al. (2012) demonstrated that the addition of sourdough in salt reduced bread prolonged shelf life to 12-14 days. Sourdough fermented with *Lactobacillus amylovorus* DSM 19280, can be used to extend the shelf life of many different products (Belz et al., 2019), including gluten-free bread (Axel et al., 2015) and cheddar cheese (Lynch et al., 2014).

7.Conclusion and future perspectives

Bakery products, especially bread, play a central role in this scenario as they are staple foods largely consumed worldwide, most times being the major contributor for excessive sodium intake. Reducing NaCl to 0.3 - 0.6 % is feasible without affecting the baking product's technological properties, but not without influencing sensory characteristics. When reducing sodium chloride levels in bakery products, it must be kept in mind the numerous roles this substance plays on techno-functional and sensory properties of the product.

Many solutions are being evaluated to avoid the negative impact of reducing sodium chloride, the most common being the slow, gradual reduction, which takes time to adapt consumers' preference for saltiness. This method has its limitations as it can take years and has a critical threshold, when sodium chloride can no longer be reduced without compromising product quality.

To preserve techno-functional and sensory properties of the product, faster alternatives are being studied, such as: the use of salt replacers, taste contrast, sourdough and clean label taste enhancers like herbs and spices. Even though these methods are able to preserve product quality, they have limitations as they impose manufacturing changes, requiring big investments for the food industry. Overall, there is still no consensus over the best method or the optimum substance level.

More studies on the different methods should be carried out to understand which one is more effective, making the manufacturers safer to invest in new formulations. A recent challenge is to achieve a clean label sodium reduction, avoiding controversial substances such as monosodium glutamate. Considering the clean label trend, sourdough and herbs and spices are promising strategies as they improve product quality with safe substances that are familiar to the consumer.

Declaration of interest

The authors declare no conflict of interest.

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Table 1

Contribution of bread to sodium intake (%) in adults worldwide.

Countries	Contribution of bread to daily sodium intake (%)	Authors	Time related
Africa			
South Africa	40.5*	Charlton et al. (2005)	2002
Tunisia	40	El Ati et al. (2021)	2015
Asia			
Japan	4.26	Asakura et al. (2016)	2012-2013
India	3.3	Johnson et al. (2019)	2014
South Korea	2.1	Park et al. (2020)	2008-2009
China	1.6	Anderson et al. (2010)	1996-1990
Europe			
Spain	35**	Guallar-Castillón et al. (2013)	2008-2010
Turkey	34	Erdem et al. (2017)	2012
United Kingdom	25	National Food Survey (2004)	2000-2001
France	24.2	Meneton et al. (2009)	1998-1999
Germany	24	Konitzer et al. (2013)	2007-2008
Italy	19.7	Malavolti et al. (2021)	2016-2017
Finland	19	Reinivuo et al. (2006)	2002
North America			
Canada	8.7	Kirkpatrick et al. (2019)	2015
Mexico	8.3	Colin-Ramirez et al. (2017)	2010-2011
USA	5.1	Drewnowski & Rehm (2013)	2003-2008

Oceania			
Australia	20	Margerison et al. (2013)	2002-2006
New Zealand	13	Eyles et al. (2016)	2011-2012
South America			
Argentina	20.3	Elorriaga et al. (2017)	2013-2014
Brazil	12.4	Mello et al. (2019)	2014-2015

*Considers only population from urban areas.

**Considers sodium intake of hypertensive participants.

Table 2

Sodium content in different baked products.

Products	**Mean sodium content (mg / 100 g)**	**Country**	**References**
Hamburger buns	439	Argentina	Allemandi et al. (2019)
Wholemeal bread	421	Argentina	Allemandi et al. (2019)
Cheese bread	804	Brazil	TBCA (2020)
Batard bread	681	Brazil	TBCA (2020)
Durum wheat bread	490	Italy	Carcea et al. (2018)
Common bread	224	Italy	Carcea et al. (2018)
White bread	444	New Zealand	Eyles et al. (2016)
French bread	1200	Tunisia	El Ati et al. (2021)
Turkish bread	1820	Turkey	Akpolat et al. (2009)
Pizza bases	459	United Kingdom	Coyne et al. (2018)
Garlic bread	484	United States	USDA (2019)
Cookies	314	United States	USDA (2019)
Puff pastry	253	United States	USDA (2019)

Table 3

Strategies for salt reduction in bakery products and their feasible reductions.

Specific method	Bakery products	Feasible reduction (%)	References
Stealth	French bread	35	El Ati et al. (2021)
Stealth	Rye and wheat bread	33	Riis et al. (2021)
Salt removal	Wheat bread	30	Antúnez et al. (2020)
Salt removal	Durum wheat bread	50	Pasqualone et al. (2019)
Salt removal	Pizza crust	15	Bernklau et al. (2017)
Commercial seawater	Neapolitan pizza	100	Iaccarino Idelson et al. (2020)
KCl, $MgCl_2$, $CaCl_2$	Wheat bread	50	Reißner et al. (2019)
Salt replacer	Wheat bread	100	Sinesio et al. (2019)
Salt replacer	Wheat bread	100	Raffo et al. (2018)
KCl	Wheat bread	100	Chen et al. (2018)
KCl	Pizza crust	25	Bernklau et al. (2017)
Thyme, lemon balm and nettle	Wheat bread	100	Wójcik et al. (2021a)
Sumac flour	Wheat bread	33	Dziki et al. (2021)
Dry sourdough from wheat flour	Wheat bread	40	Voinea et al. (2020)
Weissella cibaria MG1 and *Lactobacillus amylovorus* DSM 19280	Wheat bread	75	Belz et al. (2019)
Lactobacillus reuteri R29	Puff pastry	30	Silow et al. (2016)
Heterogeneous salt distribution	Wheat bread	30	Monteiro et al. (2021)
Heterogeneous salt distribution	Wheat bread	33	Sinesio et al. (2019)
Heterogeneous salt distribution	Pizza crust	25	Mueller et al. (2016)

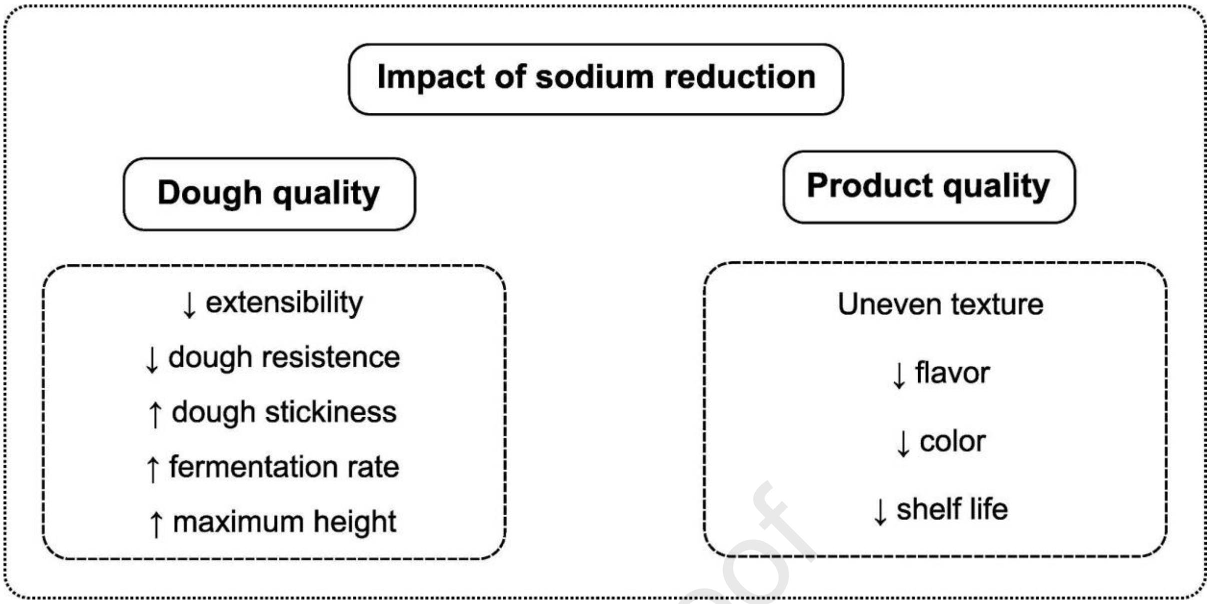

Fig. 1. Impact of sodium reduction on the decrease (↓) or increase (↑) of some dough characteristics and product quality.

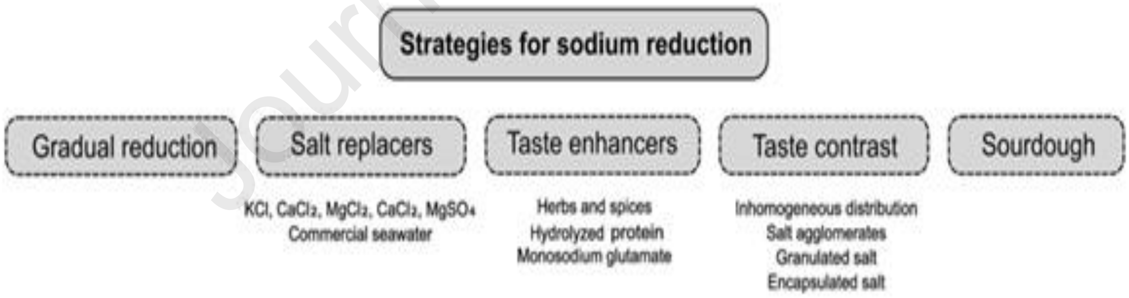

Fig. 2. Summary of different strategies for sodium reduction in baked products

Highlights

- Excessive salt intake is associated with all-cause mortality.
- Bread and other bakery products are contributors to salt intake.
- Salt reduction in bakery products can have effects on dough and final products.
- Gradual reduction is the current main strategy to reduce salt content.
- Salt replacers, taste enhancers, taste contrast and sourdough are other strategies.