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Review

Sodium reduction technologies applied to bread products and their impact on sensory properties: a review

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Abstract Chronic overconsumption of sodium has led to its designation as a nutrient of public health concern. While the current adequate intake (AI) of sodium is set at 1.5 g per day, the average daily intake for Americans ages one and up is currently above 3.5 g, leading to an increased risk of health conditions such as hypertension and cardiovascular disease (CVD). Due to the prevalence of daily bread consumption and the moderately high sodium content that accompanies it, bread has become a major contributor to dietary sodium intake. Still people seem to associate foods higher in sodium content, such as processed meats and frozen foods, as the main way to limit sodium consumption, and therefore, overlook the contribution made by regularly consuming bread. This review focuses on recent research detailing methods that are being implemented in attempts to reduce the sodium content of bread products. Included literature examined the perspective of sensory feasibility and on identifying gaps in knowledge surrounding viable strategies for producing reduced-sodium breads. Sodium reduction technologies discussed include methods in the areas of salt removal, physical modification, salt replacement and flavour modification.

Keywords Bread, consumer perception, replacement, salt, sensory evaluation, sodium reduction.

Introduction

Sodium overconsumption

Intake

Sodium overconsumption have been a cause for concern in recent years. The current adequate intake (AI) of sodium, which determines the goal average daily nutrient intake, is set at 1500 mg per day (National Academies of Sciences & Medicine, 2019). According to the Dietary Guidelines for Americans 2015–2020, sodium intake should be limited to below the tolerable upper intake level (UL) of 2300 mg per day (U.S. Department of Health & Human Services & U.S. Department of Agriculture, 2015). Comparatively, the average sodium intake of Americans ages one and up is over 200% the AI, approximately 160% the UL, and currently stands at over 3400 mg a day (Dietary Guidelines Advisory Committee, 2015).

Health effects & associated healthcare expenditure

Research has demonstrated excess sodium intake as a risk factor of chronic diseases including cardiovascular disease, hypertension, stroke, kidney disease and other non-communicable diseases (Hermansen, 2000; Newberry *et al*., 2018; National Academies of Sciences & Medicine, 2019). Given that stroke, kidney disease and hypertension are among the 15 leading causes of death in the U.S., accounting for 5.2%, 1.8%, and 1.3% of total deaths, respectively (Fig. 1) (Kenneth *et al*., 2019), it is imperative to limit overconsumption of sodium. This recommendation is further supported by the fact that nearly half of all Americans and an estimated 1.13 billion people globally have hypertension (Chobanian *et al*., 2003; Centers for Disease Control & Prevention, 2019; Yoshi, 2019). Furthermore, the estimated lifetime risk of an American developing hypertension is approximately 90% (Dietary Guidelines Advisory Committee, 2015). Evidence has been found in a variety of randomised controlled experiments that a reduction in sodium consumption can decrease the risk of these diseases (Cutler *et al*., 1997; Graudal *et al*., 2012; Aburto *et al*., 2013). Considering the directly proportional relationship between sodium intake and high blood pressure, decreasing sodium consumption has been proven to not only lower blood pressure, but to potentially lower the risk of hypertension, heart disease and stroke (Sacks *et al*., 2001; National Academies of Sciences & Medicine, 2019). In the United States, an average reduction in sodium

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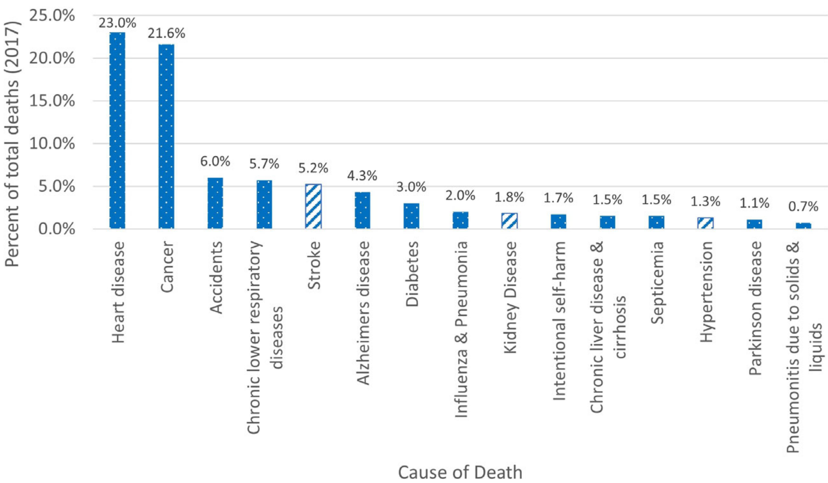

Figure 1 Top 15 leading causes of death in 2017.

intake of 1200 mg sodium per day is estimated to reduce hypertension incidence by 11 million, to prevent 44 000 to 92 000 deaths annually, as well as prevent thousands of coronary heart disease, stroke and myocardial infarction cases (Palar & Sturm, 2009; Bibbins-Domingo *et al*., 2010). In addition, with the World Health Organization (WHO)'s goal of reducing 30% salt intake by 2025, 2.5 million deaths are estimated to be prevented (Volkov, 2020). Extending beyond the prevention of the aforementioned diseases, reducing salt intake also has the potential benefit of substantially reducing healthcare expenditure and relieving monetary stress, as nearly $131 billion is spent on high blood pressure related expenses annually (Kirkland *et al*., 2018). More specifically, if the sodium intake can be reduced to 2300 mg per day, $100 billion could be saved on healthcare costs in the following decade (Bibbins-Domingo *et al*., 2010).

Sodium sources

Processed, prepackaged and restaurant foods are the main source of sodium intake, contributing approximately 71%–77% (Fig. 2) (Mattes & Donnelly, 1991; Dötsch *et al*., 2009; Harnack *et al*., 2017). The top three food categories that contribute the highest shares of salt intake in European countries include milk/dairy products, meat/meat products and bread/cereals/bakery products. Regardless of regional differences, a main dietary source of salt currently originates from the staple food category consisting of bread, cereals, and bakery products (Miller & Hoseney, 2008; Liem *et al*., 2011; U.S. Department of Health & Human Services & U.S. Department of Agriculture, 2014; Kloss *et al*., 2015). While reducing salt in bread and bakery products has been considered technologically feasible, issues surrounding acceptability of resulting flavour attributes have risen indicating more investigation into

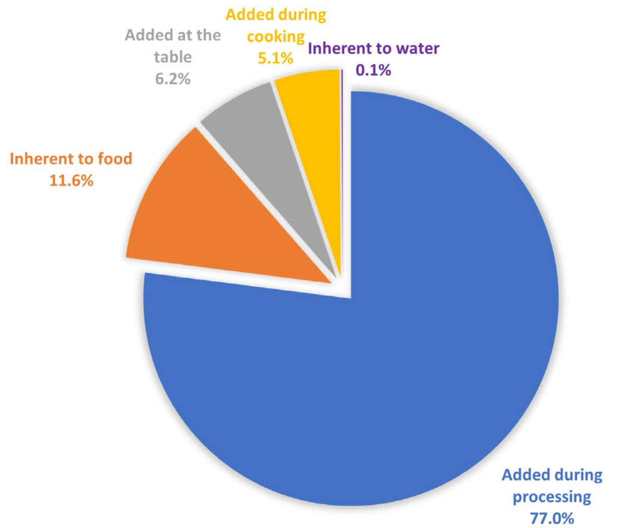

Figure 2 Sodium contributions to dietary intake.

the sensory feasibility of salt reduction in bread is necessary.

Role of salt in bread

Bread and yeast-leavened products typically require four essential ingredients: flour, salt (sodium chloride), yeast and water (Cauvain, 2015). Although the salt content in bread is minimal in respect to an entire recipe, generally set at levels only 1%–2% of the total flour weight, the inclusion of salt in bread formulation is crucial as it largely influences the technological processes that occur during breadmaking (Simsek & Martinez, 2016; Cauvain, 2019). In addition to contributing to taste attributes within the bread, salt can substantially impact the quality of the dough and baked bread as through its effect on gluten behaviour and dough expansion (Mondal & Datta, 2008; Avramenko *et al.*, 2018). When the salt content is insufficient, dough strength will weaken, experience a reduced ability to retain gas and consequently undergo improper expansion (Simsek & Martinez, 2016; Reißner *et al.*, 2019). Furthermore, salt affects bread dough by regulating the yeast activity; in the absence of salt, excessive fermentation from the yeast would lead to a gassy and sour tasting dough which will bake into a loaf with a soft, uneven crumb structure and an overall reduction in texture quality (Lynch *et al.*, 2009).

Objectives

The main objective of this review is to detail the recent literature investigating sodium reduction strategies in bread products from the perspective of sensory feasibility. The specific aims of this review were included the following: (i) determining which sodium reduction methods have been utilised in the production of bread with lower sodium content while maintaining consumer acceptance and (ii) identifying the gaps in knowledge surrounding viable strategies to reduce the sodium content in food. Sodium reduction technologies such as reduction of salt, physical modification, salt replacers and flavour modification are discussed in this review.

Methods

The literature included in this review was identified as part of a comprehensive scoping review on sodium reduction strategies being utilised in food production. The literature review aimed to identify studies conducted on titles, abstracts and/or author-provided keywords. Terms used to identify relevant studies include '(salt OR sodium) AND reduc* AND (process OR technol* OR develop* OR intervention OR strateg*) AND (consumer OR sensory) AND (liking OR hedonic OR intensity) AND (food OR product)'. After screening the literature for relevancy to the objective, articles were tagged with categorical information such as food group, sodium reduction strategy and sensory evaluation method. Articles focussed on reducing the sodium in bread products were sorted out and those published in the past five years (2017–2021) were included (Fig. 3).

Current activity

Over the course of the previous few years, researcher have continued investigating how sodium reduction can be achieved in bread products (Cappelli *et al.*, 2020a; 2020b). A variety of methods have been evaluated, including removing salt from the recipe, implementing taste contrast, substituting salt with salt replacers, and modifying the flavour profile (Table 1) (Cappelli *et al.*, 2020a; 2020b). Although investigation into using reduction of salt and salt replacement in breads have been most frequently published strategic categories in the past 50 years, flavour modification and physical modification have been increasing in frequency since approximately 2010 (Fig. 4). The variety of breads investigated was not limited to any one area as researchers tested their sodium reduction strategies on products such as white, wheat, multigrain, French and rye breads, as well as the traditional Indian poori bread. In depth details of each study are included in the following sections organised by the sodium reduction method used.

Reduction of salt

Of the strategies employed to reduce the sodium content in bread and bakery products, the most straightforward would be to reduce the amount of added salt in the recipe. While this is not a novel approach (Tuorila-Ollikainen *et al.*, 1986; Ruusunen *et al.*, 2005; La Croix *et al.*, 2015; Laranjo *et al.*, 2016; Delgado-Pando *et al.*, 2018), several recent studies have continued investigating its feasibility in the development of reduced-sodium bread without incurring loss in sensory quality. Pasqualone *et al.* (2019) evaluated the quality and acceptability of wheat durum bread prepared with a variety of salt levels (5%, 10%, 15% and 20% by flour weight). A consumer test involving habitual bread consumers was conducted where participants indicated purchase intent and ranked them according to preference. While the bread with 5 g kg^{-1} salt was largely rejected by the consumers, the preference for breads with 15 g kg^{-11} salt and 20 g kg^{-1} salt did not differ, and it was estimated that over 80% would purchase the bread with 10 g kg^{-1} salt. Next, a descriptive analysis panel characterised the 10 g kg^{-1} salt level and 20 g kg^{-1} salt level breads. Attributes significantly impacted by salt content include crumb consistency, crust colour, salty taste, sweet taste, yeasty odour and toasted odour. In particular, the bread with less salt had a less consistent crumb, a less intense crust colour, lower salty taste scores, higher sweet taste scores, a stronger yeasty odour and a weaker toasted odour. While these findings do not explicitly indicate salt reduction as a method is or is not feasible, it is important to note that only a control and a 50% salt reduction treatment were included in the descriptive analysis and that lesser reduction may limit any significant changes to quality.

Rannou *et al.* (2018) characterised and investigated the acceptability of bread with two formulations

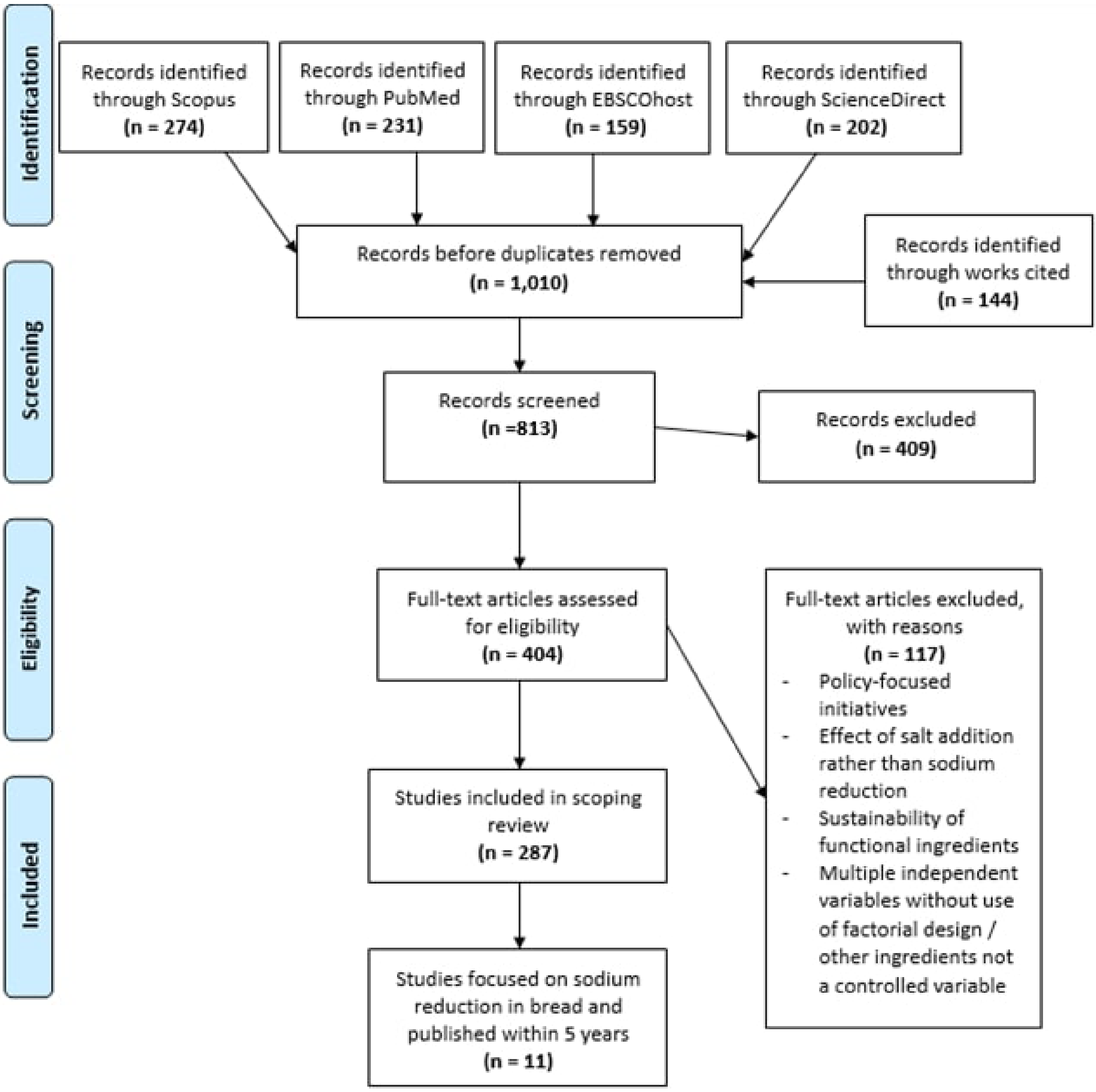

Figure 3 Flowchart documenting the scoping review and concise bread review search process.

(white and French breads) and at two salt levels (1.2 and 1.8 g kg^{-1} flour). A panel was tasked with ranking the breads (white bread with NaCl of 1.2 g kg^{-1} flour: WB12, white bread with NaCl of 1.8 g kg^{-1} flour: WB18, French bread with NaCl of 1.2 g kg^{-1} flour: FB12, French bread with NaCl of 1.8 g kg^{-1} flour: FB18) according to attribute intensities. Overall aroma was found to be significantly more intense in FB18 compared to both FB12 and WB12, while WB18 did not differ from any bread. The saltiness intensity of both full-salt breads was significantly higher than both reduced-salt breads, which did not differ from each other. Lastly, both French breads were significantly more cohesive than the white breads and higher salt content breads had higher cohesion within the bread formulation. The authors also conducted a consumer test consisting of children ages 6 to 11 for liking, saltiness intensity, and preference. Findings

Table 1 Methods of sodium reduction utilised in bread (2017–2021)

Reduction method category	Specific reduction method	Bread investigated	Salt reduction levels feasible	Note	References
Reduction of salt	Salt removal from recipe	Wheat bread	25%–50%		Pasqualone *et al.* (2019)
		White and French bread	33%	Subjects were children	Rannou *et al.* (2018)
		White and multigrain bread	0%–15%		Kuhar *et al.* (2020)
		White bread	31%		Antúnez *et al.* (2020)
	Stealth salt removal	Wheat and rye bread	33%		Riis *et al.* (2021)
Physical modification	Taste contrast	Wheat bread	33%		Sinesio *et al.* (2019)
		White bread	0%	Evaluated saltiness enhancement without salt reduction	Lee *et al.* (2020)
Salt replacers	CaCl2, MgCl2, KCl	Wheat bread	40%–50%		Reißner *et al.* (2019)
	KCl	Wheat bread	30%		Antúnez *et al.* (2018)
	KCl-based PanSalt®	Wheat bread	0%		Raffo *et al.* (2018)
		Wheat bread	0%–43%		Sinesio *et al.* (2019)
Flavor modification	Herbs & spices; Monosodium glutamate	Poories (deep fried bread)	12.5%–25%		Maheshwari *et al.* (2017)

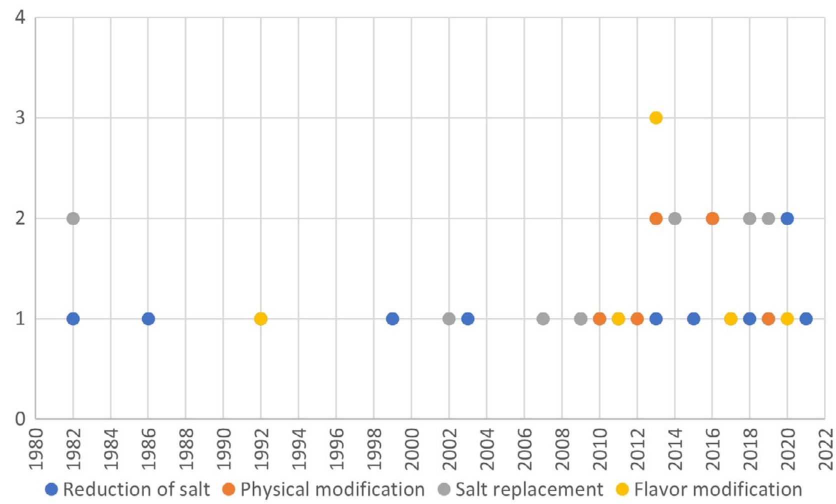

Figure 4 Frequency of sodium reduction methods in bread products published per year.

indicated that children liked FB18 significantly more than WB12, which did not differ in liking from FB12 or WB18. Children also preferred the French breads over the white breads, although neither salt level was preferred over the other. Surprisingly, children did not perceive differences in the saltiness intensity between either bread formulation or salt level. As a whole, the authors concluded that the salt-reduced breads were well-accepted by children.

Kuhar *et al.* (2020) assessed how salt content influences consumer' liking and saltiness perception in white and multigrain breads. Treatments evaluated include a control with salt content based on Slovenia's national average in bread, a reduced treatment with

15% less salt than the control and an increased treatment with 10% greater salt than the control. A consumer test was conducted in that 200 regular bread consumers rated their liking and saltiness perception of each bread sample, as well as completed a questionnaire for further evaluation into consumer segmentation. Hedonic liking of the white bread was not found to be influenced by salt concentration; however, the multigrain bread was affected significantly with the reduced sample liked less than the control. The bread type was found to be a significant factor in consumer liking with the white bread being liked more than multigrain bread regardless of salt concentration. In respect to saltiness perception, no difference across samples emerged and all were perceived to be slightly below Just-about-right for saltiness intensity including those with salt levels higher than the national average. Consumer segmentation was evident in which three distinct groups were identified. The first group (~69%) of participants were 'salt indifferent', the second group (~22%) were 'salt adherent' and rated all samples as having not enough salt and the third and final group (9%) was considered 'salt sensitive' and rated all samples as having too much salt. The 'salt adherent' group are aware of their excessive salt use at the table but are significantly less conscientious about limiting their consumption of salt. An issue surrounding consumer knowledge on the subject is evident as all three groups believed selecting breads with lower salt content as the least effective method to reduce salt intake and that the most effective would include limiting salt addition during cooking or at the table.

Antúnez *et al.* (2020) investigated consumers' reactions to salt reduction in white bread with and without sodium warnings. Under blind and informed conditions, consumers rated overall liking and indicated their preference of 1.38% and 2.00% salt bread samples. Overall liking for the 2.00% salt bread was significantly higher than the 1.38% bread, although the difference was smaller in the informed condition. Regarding preference, consumers fell into two segments; the 2.00% salt bread was preferred by 58% of consumers, whereas 42% preferred the 1.38% salt bread. Regardless of their salt preference, the presence of a sodium warning was found to encourage consumers to choose breads with reduced-salt content and to shift consumer preference towards lower sodium breads after re-tasting.

Riis *et al.* (2021) investigated how salty taste thresholds and overall liking were influenced by gradually reducing the salt content of wheat and rye breads over 4 months either with or without dietary counselling. While gradually reducing salt content, also referred to as the stealth method, did not incur any significant changes in salty taste thresholds at follow-up, those who received gradually reduced-salt breads alongside dietary counselling had significantly lower detection thresholds, while those without dietary counselling and those in the control group without salt reduction had not. At baseline, bread with 0.4 g kg^{-1} was liked less by all groups than the 0.8 and 1.2 g kg^{-1} breads which were not different from one another. At follow-up, all groups experienced a reduction in liking of the 1.2 g kg^{-1} bread and liked the 0.8 g kg^{-1} bread significantly more than the 0.4 and 1.2 g kg^{-1} breads. While this reduction in liking of the highest salt bread may indicate a shift in salt preference of bread over time, the authors state that it is more likely due to the possibility that participants became aware of the salt reduction focus and inadvertently become biased towards favouring lower salted breads. In comparing the groups, it was found that those who had dietary counselling in addition to the gradual reduction of salt in bread liked the 0.4 g kg^{-1} bread significantly more than the control group, while the group with gradual salt reduction alone trended towards higher liking of the 0.4 g kg^{-1} bread. Although neither salt-reduced breads experienced an increase in liking over time, it is worth noting that neither the 1.2 g kg^{-1} or the 0.8 g kg^{-1} breads were significantly liked any more or less at baseline than the other, indicating an outright 33% reduction in salt may not negatively influence liking. Dietary counselling may also prove useful in lowering one's salty taste detection threshold and subsequently shift salt preference.

The feasibility of sodium reduction in a wide variety of breads have been explored in recent years and have shown varying levels of acceptable reduction. Sodium reduced white, wheat and French breads incurred the least resistance from consumers and findings from this review indicate roughly 15%–25% salt reduction can be safely executed with greater reduction levels possible when packaging includes sodium warnings. More research into how salt removal from multigrain bread formulation is necessary as consumers liked the salt-reduced multigrain bread significantly less than the control. While Slovenia's national average for salt in bread is less than other countries and, therefore, contain less salt than in other studies, investigation into how the salt reduction influences flavour development in multigrain bread in specific is needed. Past simply removing salt from the formulation, the stealth method of gradually reducing salt in a product over time may not be feasible for commercially available bread due to the time demands, the requirement of other bread manufacturer's compliance, and similarly the relative simplicity of purchasing a bread that does not implement sodium reduction or the stealth approach. Despite the low feasibility for bread in the market, the stealth approach shows promise for use in reducing an individual's sodium intake when used in conjunction with dietary counselling. A larger issue arising from recent literature on the subject indicates that consumers are unaware of the contribution that bread has on sodium intake. Combined with the findings that sodium warnings can increase acceptability of salt-reduced breads, consumer education on major sodium sources in the diet may prove useful in raising consumer awareness of their sodium consumption from processed foods.

Physical modification

A method similar in formulation maintenance to salt removal is physical modification. While this method can be characterised by a variety of different approaches, such as salt encapsulation (Noort *et al.*, 2012; Kwon *et al.*, 2019) and high pressure processing (Pietrasik *et al.*, 2016; Orel *et al.*, 2020), the taste contrast method by inhomogeneous spatial distribution of salt is the focus in recent sodium reduction research in bread. In a study conducted by Sinesio *et al.* (2019), the efficacy of an inhomogeneous distribution of salt to enhance saltiness was evaluated in wheat bread. Treatments consisted of a 1.5% NaCl control bread, a 1.0% NaCl bread and a 1.0% NaCl bread with an inhomogeneous salt distribution. Descriptive analysis revealed that the reduced-salt bread with inhomogeneous salt distribution maintained olfactory and consistency characteristics of the control bread, and that it did not differ in regard to overall flavour or salty taste intensity. Consumer testing was implemented to obtain hedonic evaluations from 203 bread consumers. Primary results include that consumers could not discriminate between either 1.0% NaCl breads regardless of NaCl distribution and that both 1.0% salt breads were associated with terms with negative valence. Consumer testing also revealed segmentation in which one group (42%) did not find taste contrast effective, a second group (27%) which could not discriminate between either distribution of reduced-salt breads, and a third group (31%) which could not discriminate between the reduced-salt bread with taste contrast and the full-salt bread and which preferred and perceived the reduced-salt bread with taste contrast as saltier than homogeneous reduced-salt bread. While the efficacy of taste contrast by inhomogeneous salt distribution to reduce salt in breads differed by target consumer group, it was concluded that utilising inhomogeneous salt distribution could successfully reduce salt by 33% without a loss of saltiness or other discriminatory attributes.

Physical modification in bread has also been investigated Lee *et al.* (2020), where researchers evaluated the ability for a spray-dried salt-yeast complex to enhance the saltiness of white bread. Through their methodology, researchers incorporated aspects of physical modification and taste contrast by spray-drying of salt-yeast complexes leading to an inhomogeneous distribution of the salt during fermentation. While the treatments focussed on varying ratios of salt to yeast rather than levels of sodium reduction, their methods of research remain relevant to the scope of this review as it investigated saltiness enhancement. Descriptive analysis revealed that the crumb of the bread with the salt-yeast complex ratio of 20:3 was significantly more intense in saltiness than the control with raw yeast and salt separated. Similarly, it was also found that the saltiness of the bread crust with the salt-yeast complex ratio of 20:9 was preferred over the saltiness of the control although not significantly, and that overall acceptability of the 20:3, 20:6, and 20:9 breads were comparable to the control acceptability. Despite these promising results demonstrating the use of a spray-dried salt-yeast complex to enhance saltiness and possibly preference, future research will need to be conducted to determine whether positive outcomes of comparable acceptability, preference and an increased saltiness remain when the sodium content is reduced.

Physical modification by taste contrast using inhomogeneous salt distribution has been proven to be a promising salt reduction method, where a 33% reduction in salt could be achieved in bread with no significant differences evident in either descriptive sensory attributes or consumer perception. Another physical modification method utilising inhomogeneous distribution incorporates the spraying of aqueous salt solution on pizza crust and further gives evidence to the potential of taste contrast in improving saltiness and reducing salt consumption in bakery products. Besides taste contrast, physical modification methods like encapsulating salt crystals to prevent dissolution, modifying crumb texture to allow a faster sodium release and applying coarse or nano spray-dried salt crystals all demonstrate the ability to affect salt taste perception and enhance salt intensity albeit not yet investigated in bakery products. Because bread and other bakery goods are a main sodium intake source and research on reduced-sodium bread is currently limited, more research should be conducted to investigate the potential of other physical modification methods as a salt reduction strategy on bakery products.

Salt replacers

A prominent approach used to reduce the sodium content of foods is to utilise salt replacers (Grummer *et al.*, 2012; Ayyash *et al.*, 2013; Paulsen *et al.*, 2014). Partial substitution of sodium chloride (NaCl) with other mineral salts such as potassium chloride have been successful up to certain limits, above which may confer an off taste. This approach has also been investigated in bread systems in years past (Salovaara, 1982; Wyatt & Ronan, 1982; Charlton *et al.*, 2007). More recently, Reißner *et al.* (2019) investigated whether substituting NaCl with mixtures of potassium chloride (KCl), magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$) in wheat bread would cause a noticeable difference from a NaCl bread. Discrimination testing revealed that all breads were identified as different from the control, apart from the 50% KCl and the 40% KCl with 10% $MgCl_2$ breads. Those containing both $MgCl_2$ and $CaCl_2$ were all correctly discriminated as different by over 90% of consumers, while those containing $CaCl_2$ were identified correctly by over 85%. These findings suggest that KCl can be utilised to aid in sodium reduction to produce a bread comparable to the reference and that $MgCl_2$ may be feasible as a salt replacer in small quantities alongside other methods.

KCl's feasibility as a salt replacer was investigated in wheat bread by Antúnez *et al.* (2018). A trained panel characterised bread containing a variety of NaCl:KCl blends using a temporal Check-All-That-Apply method and found that substituting 30% NaCl produced a bread with a similar sensory profile, although once substitution levels reached 40% and above, an increase in the observation of a metallic attribute occurred. As the 70:30 NaCl:KCl has the most similar profile, a consumer test was conducted on breads containing either NaCl at various levels or the blend at corresponding equivalent saltiness concentrations. Results suggest that consumers liked breads with higher sodium content regardless of whether NaCl or the NaCl:KCl blend was used and that a 30% replacement of NaCl with KCl did not increase the frequency of the terms metallic, bitter or off-flavor to be used in describing the breads. Consumer segmentation was evident where one group preferred wheat breads utilising NaCl only, where the second group preferred those made with the NaCl:KCl blend, although their perception towards the blend was primarily associated with differences in textural attributes.

Extending past purely KCl being used to replace NaCl, Sinesio *et al.* (2019) and Raffo *et al.* (2018) evaluated the impact of the KCl-based salt replacer, PanSalt®, on salt-reduced wheat breads. Regarding the sensory profiling of wheat breads with either 1.5% or 3% of either NaCl or PanSalt®, Raffo *et al.* (2018) indicated that replacement with PanSalt® at both addition levels failed to maintain the saltiness level and were significantly sweeter compared to the NaCl counterparts. They also noted that the crust of the 3% PanSalt® bread contributed a bitterer aftertaste than the NaCl breads. In addition to utilising descriptive analysis to obtain a sensory profile of the wheat breads, Sinesio *et al.* (2019), mentioned earlier regarding taste contrast, additionally conducted a consumer test to evaluate consumer perception of the breads. Sensory profiling revealed that using 1.5% PanSalt® failed to preserve the saltiness of the 1.5% NaCl bread, although the overall flavour intensity did not differ, and no undesirable flavours were perceived. The consumer test results indicated that the overall liking did not differ between the 1.5% NaCl and 1.5% PanSalt® breads. Characteristics used to describe the 1.5% PanSalt® bread include *good taste* and *texture* and the *right saltiness* whereas the 1.5% NaCl bread was described by *liking of flavour, texture* and *no negative aspects*. As discussed in the taste contrast section of this review, consumer segmentation revealed the sodium reduction strategies were not effective for one group, comprising 42% of consumers, while two groups found PanSalt® to be either as or more salty than the 1.5% NaCl bread. These results suggest that PanSalt®, and potentially other KCl-based replacers by extension, may impact the overall flavour perception rather than the perception of salty taste and that consumers' perception of these reduction methods will depend on the target consumer group.

Investigation into the salt replacer method has demonstrated KCl as an appropriate partial substitute for NaCl by imparting bread properties and sensory perception qualities comparable to reference breads. In contrast, partial or complete replacement by other salt replacers like $CaCl_2$, $MgCl_2$ or KCl-based PanSalt® were unable to achieve the same acceptable results. Resulting breads containing the aforementioned salt replacers were associated more with off-flavor and bitterness attributes, although combining lesser amounts of $MgCl_2$ with other sodium reduction methods seems to be feasible. While there is a relatively comprehensive understanding of salt replacement as a sodium reduction strategy, its use is limited to determine the quantity able to be replaced without affecting the product characteristics and sensory attributes. Because of this, the combination of salt replacers with other methods like flavour enhancers exhibits a strong possibility and warrants future research.

Flavor modification

Modifying the flavour of a product is one of the broadest categories of methods to mitigate quality loss in products as sodium content is reduced. They can be as conventional as incorporating herbs and spices into the recipe (Mitchell *et al.*, 2013; Wang *et al.*, 2014) or as controversial as adding monosodium glutamate (MSG). A promising way to keep a similar, but more intense flavour profile while achieving sodium reduction is through the use of flavour potentiators, such as MSG, as they enhance the natural flavour in a product and may heighten saltiness perception (Roininen *et al.*, 1996; Kim *et al.*, 2014; Jinap *et al.*, 2016). Maheshwari *et al.* (2017) investigated the flavour potentiating effect of MSG on salt-reduced plain and spiced poori bread, a traditional Indian bread. A semi-trained panel evaluated the poori breads at salt reduction levels of 12.5% and 25% and at two levels of MSG addition. When compared to the full-salt control, the plain breads with MSG were scored higher for overall quality, and no differences were found between the different salt levels of the bread containing MSG. Additionally, the plain bread had maintained acceptability at both levels of salt reduction. These findings demonstrate that MSG addition successfully increased the taste profile of plain poori bread at reduced levels of added salt. Inclusion of spices, another method of flavour modification, was also investigated in this research project in attempts to evaluate MSG's synergistic properties. Poori breads were prepared with various singular or spice mixtures, 12.5% or 25% salt reduction, and two levels of MSG addition. Panelists rated the salt-reduced spiced bread with MSG to be either the same or greater in regard to overall quality at all treatment levels when compared to the control, as well as equally liked for the evaluated sensory attributes. Most promising was that the highest scores were obtained by the spiced breads with 12.5% salt reduction and added MSG indicating that the inclusion of MSG had a synergistic effect with the investigated spices through enhancing various flavour properties.

Despite many options available for sodium reduction based on flavour modification, research on how they may be used on bread and bakery products has been lacking in recent years. Given the absent differences in desirable sensory attributes between the reduced-salt breads with MSG and the breads without salt reduction, it appears that it would be valuable for MSG to be investigated at differing quantities and on a wider variety of salt reduction levels. The apparent synergistic effect between MSG and certain spices lending to the quality and acceptability of salt-reduced poori bread further demonstrates that MSG should be studied alongside other flavour modification methods in food products struggling with minimal flavour such as low-sodium or sugar-free products.

Considerations

While many options exist out there to reduce the sodium content in food, investigation specific to bread in recent years is not comprehensive. There exists room to improve so that further reductions in sodium content can be achieved. Considerations in selecting a method appropriate for bread, as well as many other food products, are abundant. Many methods require additional ingredients that will cost the manufacturer more than will be saved from the reduction in added salt. In addition to the cost implications to be considered, the environmental impact of these strategies must be considered as sustainability needs to be prioritised when making innovations or improvements (Cappelli *et al.*, 2021). Physical modification methods may require new processing equipment if the manufacturing plant is specialised to one product, and are, therefore, also to be considered in capital costs. The additional ingredients in certain methods may also impact consumers' willingness to purchase the product if the ingredient in question is unfamiliar to them. A 'clean label' in individuals' minds cannot be achieved with certain methods, such as using MSG. A final consideration to make is how consumer segmentation affects the overall chance of success for the product. By identifying what sensory characteristics different consumer segments value most in their breads, product development can be guided towards specific sodium reduction methods deemed important by the most predominant segments.

Conclusions and future research

The reduction of sodium content in bread and other bakery products can adversely affect consumers' perception of the overall palatability. To reduce excessive intake of sodium from bread, a variety of methods have been investigated in attempts to mitigate a loss of consumer acceptability. The most simple and cost-effective method is reducing the amount of salt in the recipe. Depending on the sodium content of the full-salt product, a reduction of 15%–25% salt appears feasible for most types of bread with some as significant as a 33% reduction in salt. Further reductions may have better reception in the market if consumer education is implemented such that bread can become known as a sizeable source of sodium. Valuable aims for future research pertinent to salt removal from bread include determining minimum concentrations of sodium required for different bread varieties before consumers can discriminate the product from a full-salt control and identifying key attributes which consumers use to discriminate reduced-sodium breads.

When it is preferable that a formulation remain the same apart from some level of salt removal, physical modification may be utilised to reduce sodium content. Reduced-sodium bread has been investigated using the physical modification method of inhomogeneous distribution and taste contrast with promising results through enhancing the perception of saltiness. It could be worthwhile for researchers to consider how much salt or sodium concentration difference is optimal for utilising taste contrast in various products. Investigation of other methods of physical modification for the purpose of sodium reduction in bread products would also be valuable given the limited scope of those detailed in recent years.

The method most investigated behind salt removal is the use of salt replacers, particularly KCl, in place of a portion of the salt, or NaCl. Due to the abundance of research recently and in the past regarding KCl alone and in conjunction with other mineral salt replacers, it would be beneficial for future research to include aims such as to evaluate KCl as a salt replacer in conjunction with other sodium reduction methods, such as certain flavour modifications.

In recent years, flavour modification in bread as a method to reduce sodium has been limited to the flavour potentiator, monosodium glutamate, in conjunction with spices. Results were promising as monosodium glutamate breads with reduced-salt were comparable to control breads in evaluated attributes and because synergism appeared to enhance the flavour of salt-reduced poori bread when spices were included. Further research into flavour modification methods, particularly those with the potential to synergistically enhance flavour, is necessary so that both nutritional and sensory quality can be optimised for achieving a healthier sodium intake.

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Conflict of interest

None.

Author contributions

Aubrey Noelle Dunteman: Conceptualization (equal); Data curation (equal); Formal analysis (lead); Investigation (lead); Methodology (lead); Visualization (lead); Writing-original draft (lead); Writing-review & editing (equal). **Ying Yang:** Data curation (equal); Writing-original draft (equal); Writing-review & editing (supporting). **Elle McKenzie:** Data curation (equal); Writing-review & editing (supporting). **Soo-Yeun Lee:** Conceptualization (equal); Funding acquisition (lead); Project administration (lead); Resources (lead); Supervision (lead); Writing-review & editing (equal). **Youngsoo Lee:** Funding acquisition (equal); Project administration (equal); Resources (equal); Supervision (equal); Writing-review & editing (equal).

Compliance with ethics requirements

There were no human or animal subjects involved in the study conducted to write this review article.

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