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

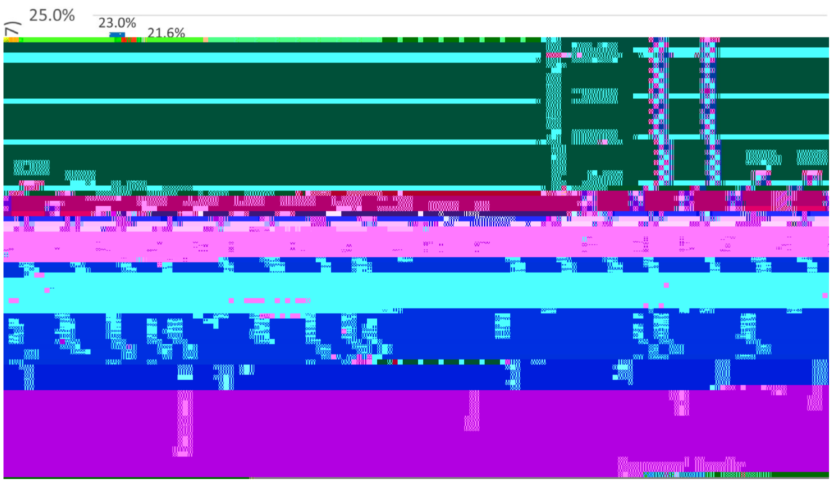

Figure 1 Top 15 leading causes of death in 2017.

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).

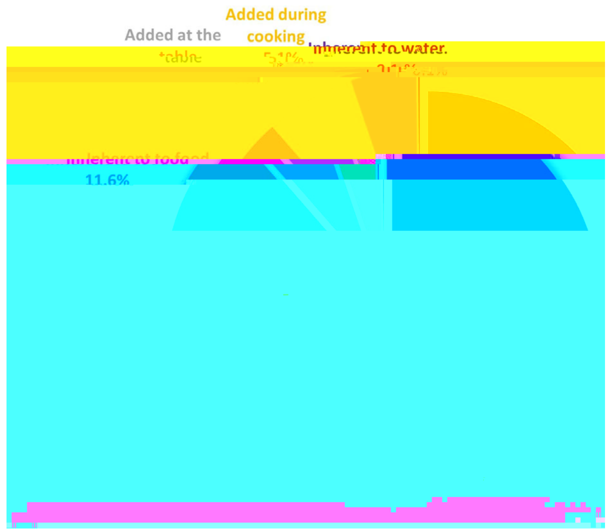

Figure 2 Sodium contributions to dietary intake.

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 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

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				

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 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

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 di□erence from a NaCl bread. Discrimination testing revealed that all breads were identified as di□erent 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 di□erent 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 o□-flavor to be used in 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

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

detection, evaluation, and treatment of high blood pressure: the JNC 7 report. JAMA , 289, 2560–2572.

Cutler, J.A., Follmann, D. & Allender, P.S. (1997). Randomized trials of sodium reduction: an overview. The American journal of clinical nutrition, 65, 643S–651S.

Delgado-Pando, G., Fischer, E., Allen, P., Kerry, J.P., O'Sullivan, M.G. & Hamill, R.M. (2018). Salt content and minimum acceptable levels in whole-muscle cured meat products. Meat Science, 139, 179–186.

Dietary Guidelines Advisory Committee (2015). Scienti“c Report of the 2015 Dietary Guidelines Advisory Committee: Advisory Report to the Secretary of Health and Human Services and the Secretary of Agriculture. Washington, DC: U.S. Department of Agriculture, Agricultural Research Service.

Dötsch, M., Busch, J., Batenburg, M. et al. (2009). Strategies to reduce sodium consumption: a food industry perspective. Critical Reviews in Food Science & Nutrition, 49, 841–851.

Graudal, N.A., Hubeck-Graudal, T. & Jürgens, G. (2012). E□ects of low-sodium diet vs. high-sodium diet on blood pressure, renin, aldosterone, catecholamines, cholesterol, and triglyceride (cochrane review). American Journal of Hypertension, 25, 1–15.

Grummer, J., Karalus, M., Zhang, K., Vickers, Z. & Schoenfuss, T.C. (2012). Manufacture of reduced-sodium Cheddar-style cheese with mineral salt replacers. Journal of Dairy Science, 95, 2830–2839.

Harnack, L.J., Zhou, X., Ste□en, L.M. et al. (2017). Sources of sodium in US adults from 3 geographic regions. Circulation, 135, 1775–1783.

Hermansen, K. (2000). Diet, blood pressure and hypertension. British Journal of Nutrition, 83, S113–S119.

Jinap, S., Hajeb, P., Karim, R., Norliana, S., Yibadatihan, S. & Abdul-Kadir, R. (2016). Reduction of sodium content in spicy soups using monosodium glutamate. Food & Nutrition Research, 60, 30463.

Kenneth, D.K., Sherry, L.M., Jiaquan, X. & Elizabeth, A. (2019). Deaths: Final Data for 2017 National Vital Statistics Reports. Hyattsville, MD: National Center for Health Statistics.

Kim, B.S., Lee, J.G., Choi, M.J., Chun, J.Y., Min, S.G. & Cho, H.Y. (2014). E□ect of NaCl/monosodium glutamate (MSG) mixture on the sensorial properties and quality characteristics of model meat products. Korean Journal for Food Science of Animal ResourcesCutler, 2A1JF... 6(S76.]TJ/F61Tf2.10550TD()Tj/F41Tf.49790TD(85ej/F5v(NaRA2-1.1239TD[(Kirkland,)-329.6

Roininen, K., Lähteenmäki, L. & Tuorila, H. (1996). Effect of umami taste on pleasantness of low-salt soups during repeated testing. Physiology & Behavior, 60, 953–958.

Ruusunen, M., Vainionpää, J., Lyly, M. et al. (2005). Reducing the sodium content in meat products: the effect of the formulation in low-sodium ground meat patties. Meat Science, 69, 53–60.

Sacks, F.M., Conlin, P.R., Svetkey, L.P. et al. (2001). Effects on blood pressure of reduced dietary sodium and the dietary approaches to stop hypertension (dash) diet. New England Journal of Medicine, 344, 3–10.

Salovaara, H. (1982). Sensory limitations to replacement of sodium with potassium and magnesium in bread. Cereal Chemistry, 59, 425–430.

Simsek, S. & Martinez, M.O. (2016). Quality of dough and bread prepared with sea salt or sodium chloride. Journal of Food Process Engineering, 39, 44–52.

Sinesio, F., Raffo, A., Peparaio, M. et al. (2019). Impact of sodium reduction strategies on volatile compounds, sensory properties and consumer perception in commercial wheat bread. Food Chemistry, 301, 125252.

This paper provides important data on how physical modification by way of taste contrast and inhomogenous distribution of salt in bread can be applied to reduced-sodium wheat bread.

Tuorila-Ollikainen, H., Salovaara, H. & Kurkela, R. (1986). Effect of saltiness on the liking and consumption of bread and butter. Ecology of Food and Nutrition, 18, 99–106.

U.S. Department OF Health and Human Services and U.S. Department of Agriculture (2014). What We Eat in America. Agricultural Research Service Website.

U.S. Department of Health and Human Services and U.S. Department of Agriculture (2015). 2015–2020 Dietary Guidelines for Americans, 8th ed.

Volkov, S. (2020). Salt Reduction [Online]. Geneva: World Health Organization. Available, [Accessed 2021]. https://www.who.int/news-room/fact-sheets/detail/salt-reduction

Wang, C., Lee, Y. & Lee, S.Y. (2014). Consumer acceptance of model soup system with varying levels of herbs and salt. Journal of Food Science, 79, S2098–S2106.