

Review Article

Dietary sodium reduction through salt substitutes and enhancers: Types, applications and health implications

Alvina Rose^{1*}¹ R&D Associate, Novel Nutrilab, Teresian Innovation and Business Incubation Council (TIBIC), St. Teresa's College, Ernakulam, Kerala, India* Corresponding author: alvinarose666@gmail.com

Abstract - Sodium chloride (NaCl), commonly known as table salt, is an essential ingredient in the food industry that enhances flavor, creates texture and preserves food. On the other hand, consuming too much salt has been connected to several health problems, such as cardiovascular diseases, hypertension, bone demineralization and gastric cancers. Additionally, potential drawbacks related to impaired kidney function should be noted, particularly for individuals with chronic kidney disease (CKD), as reduced renal filtration capacity can worsen electrolyte imbalance and increase the health risks associated with certain salt substitutes. With customers' growing awareness of nutrition and health issues, low-sodium food items are becoming more and more popular. This review explores various approaches to reducing sodium in foods through salt-replacement and enhancement strategies while maintaining desirable sensory and functional properties. A comprehensive review of existing studies was conducted to identify different salt substitutes and salt enhancers. Numerous sodium substitutes, such as potassium chloride, calcium chloride, magnesium chloride and magnesium sulfate, have been assessed for their sensory qualities and functional roles. Additionally, natural and chemical flavor enhancers were examined for their ability to compensate for the reduced saltiness perception. Among the evaluated substitutes, potassium chloride and calcium chloride were the most widely used salt replacers. Major research gaps include limited long-term toxicological evaluations, inconsistent sensory outcomes across matrices and insufficient studies on

Received: 2nd November 2025,**Revised:** 3rd December 2025,**Accepted:** 3rd December 2025

Citation: Rose, A. (2026). Dietary sodium reduction through salt substitutes and enhancers: Types, applications and health implications.

Food Agricultural Sciences and Technology (FAST), 12(2), 136-154.

<https://doi.org/10.14456/fast.2026.11>

synergistic combinations of substitutes and enhancers. This review emphasizes that integrating partial mineral substitution with natural flavor enhancement is the most effective approach for developing healthier food products without compromising quality.

Keywords: Sodium chloride, cardiovascular diseases, hypertension, salt substitutes, salt enhancers

1. Introduction

Food is essential to maintaining life and guaranteeing an organism's growth and development. It offers vital nutrients and bioactive substances needed for health, maintenance and vitality. The main source of food produced for human consumption is still agriculture (Clapp, 2020). Food quality, safety and nutritional value are therefore becoming more and more important as the global food business continues to grow quickly (Belasco, 2008).

Table salt, or sodium chloride (NaCl), is one of the numerous substances used in food preparation that is essential for improving the flavor, consistency and shelf life of food. Due to its affordability, accessibility and versatility, salt is utilized extensively in a variety of food industries (Albarracín et al., 2011). Inhibiting enzymatic activity in food, decreasing oxygen solubility and decreasing water activity are some of its distinctive properties. By raising the osmotic pressure and causing microbial cell rupture, these effects work together to inhibit microbial growth (Taladrid et al., 2020).

Salt plays a critical role in food preservation and processing. During curing, it dehydrates food tissues, which lowers the amount of water available for microbial and enzymatic activity. While some halotolerant bacteria, such as *Staphylococcus aureus* and *Listeria monocytogenes*, can survive in saline environments, the presence of salt reduces the growth of some dangerous germs, including *Clostridium perfringens* and *Clostridium botulinum* (Elias et al., 2020). Salt enhances the water-holding capacity,

softness and general palatability of meat and meat products (Aprilia et al., 2022). Salt improves dough strength, stabilizes the gluten network and affects fermentation pace in baked goods (Elias et al., 2020). Similarly, salt controls microbial culture activity, protein coagulation and the development of ideal texture and body in cheese (Sun et al., 2021). Salt performs these functional roles due to its electrolyte properties and its influence on protein-water interactions. Sodium and chloride ions increase the ionic strength of food systems, which enhances protein solubility and promotes protein unfolding, enabling better emulsification and fat binding. Through electrostatic screening, NaCl reduces repulsive forces between protein molecules, facilitating protein-protein aggregation that contributes to thickening and gelling. Additionally, salt binds free water molecules through ion-dipole interactions, reducing water activity and improving moisture retention in food matrices (Elias et al., 2020).

Despite these sensory and technological benefits, eating too much salt can have major negative health effects. Consumers are demanding low-sodium or sodium-reduced food products as a result of diet-related diseases being more widely known (Sun et al., 2021). "Low-sodium" foods typically contain ≤ 140 mg sodium per serving, whereas "sodium-reduced" foods must demonstrate at least a 25% reduction in sodium content compared with the standard product formulation. Thus, sodium-reduced foods may still contain moderate sodium levels, while low-

sodium foods must meet a fixed regulatory threshold (Dötsch et al., 2009). High salt consumption has been associated in epidemiological studies with elevated blood pressure, which is a key risk factor for stroke, renal disease and cardiovascular diseases (Elias et al., 2020). According to Taladrid et al. (2020), data from the United States indicate that approximately 77% of dietary salt comes from processed foods, 12% from naturally occurring sources and only 11% from salt added during cooking or at the table. In comparison, studies from the United Kingdom and Japan reveal similar trends, with processed foods contributing to 65-80% of total sodium intake, highlighting regional variability in dietary salt sources. Additionally, excessive sodium consumption is linked to stomach cancer, especially in communities with high salt intake, including Brazilian and Japanese immigrants in the United States (Tsugane, 2005). Furthermore, excessive salt intake may negatively affect bone health by increasing calcium excretion, lowering blood pH and contributing to bone density loss and deformities (Doyle & Glass, 2010).

Reducing sodium intake in the diet has become a public health priority due to these health consequences. Researchers have looked into several methods to lower the amount of sodium in food, including using natural and chemical flavor enhancers, changing the structure of sodium crystals to improve their dissolution and perceived saltiness and replacing sodium chloride with other salts (like potassium chloride) (Elias et al., 2020). Salt substitutes and enhancers can be systematically grouped into three primary categories to improve clarity and organization in sodium-reduction strategies: (i) Mineral-based substitutes include potassium chloride, potassium lactate, calcium chloride, magnesium chloride, magnesium sulfate and lithium chloride. These compounds mimic sodium

chloride's ionic properties and influence water activity, protein interactions and microbial stability (Cepanec et al., 2017; Alino et al., 2010); (ii) Umami-based natural and biochemical enhancers such as yeast extract, hydrolyzed vegetable protein, spices, herbs, monosodium glutamate, disodium inosinate and disodium guanylate. These ingredients amplify flavor perception, enabling sodium reduction without compromising palatability (Grummer et al., 2013; Brandsma, 2006) and (iii) Technological and functional ingredients includes compounds used to modify texture, water retention, gelling and protein solubility, such as calcium salts, which compensate for structural changes during NaCl reduction (Cáceres et al., 2006; Yu et al., 2022).

A significant gap in the production of foods with lower sodium content that yet have consumer-acceptable taste, texture and shelf life persists despite a great deal of study. However, the practical usage of salt substitutes is limited because many of them add metallic or unpleasant tastes. Further research is necessary to determine the long-term safety and synergistic benefits of natural flavor enhancers, despite their encouraging initial results. With an emphasis on their processes, uses, sensory implications and safety considerations in diverse food systems, this review seeks to critically evaluate the body of work on salt replacers, flavor enhancers and salt replacements. Finding possible breakthroughs and research avenues that can support the creation of low-sodium, healthier food products without sacrificing their efficacy, quality, or customer acceptability is the goal of this review.

2. Sodium chloride

Sodium (Na^+) and chloride (Cl^-) ions are combined in a 1:1 stoichiometric ratio to form sodium chloride (NaCl), also referred to as table salt (Elias et al., 2020).

At room temperature, it is a crystalline solid with a high melting and boiling point as well as high water solubility. Transparent and colorless crystals are formed when sodium chloride crystallizes into a characteristic cubic lattice structure. Because of its physicochemical characteristics, it is an essential ingredient in a variety of industrial and chemical processes, such as the production of sodium hydroxide, chlorine and other sodium-based compounds, in addition to food applications (Feldman, 2000).

2.1. Role of salt in the food industry

Table salt is one of the most widely used ingredients in the food industry because of its multifunctional properties. It also acts as a texture modification, processing aid and preservative in addition to adding a distinctive salty flavor. The main reason sodium chloride has a preservation effect is that it can reduce water activity (a_w), which prevents microbiological growth and enzymatic spoiling. In curing, pickling and fermentation, salt is essential because it regulates the microbial flora, improves safety and stabilizes the development of flavor (Dötsch et al., 2009). Sodium chloride helps meat and meat products retain water and enhances their juiciness, water-holding capacity and protein solubility, all of which are necessary for a desired texture and binding qualities (Aprilia et al., 2022). Salt improves dough strength, controls the rate of fermentation, encourages the creation of gluten networks and adds to the overall sensory quality of baked goods (Elias et al., 2020). Similar to this, it governs microbial activity, moisture content and the development of texture and flavor in dairy products, particularly cheese (Sun et al., 2021). All of these functions highlight sodium chloride's importance as a sensory and functional enhancer in a variety of food matrices.

2.2. Health implications

The principal dietary source of sodium, a necessary mineral for preserving cellular homeostasis, osmotic pressure and electrolyte balance, is sodium chloride (Pateiro et al., 2021). In addition to facilitating the intestinal absorption of nutrients, including glucose, amino acids and water, it is essential for nerve impulse transmission, muscular contraction and acid-base homeostasis. Recommended sodium limits vary by age: children aged 1-3 years should consume <1.2 g/day of sodium chloride, children aged 4-8 years <1.9 g/day, adolescents 9-13 years <2.2 g/day and those aged 14 years and above follow the adult recommendation of <5 g/day of salt (<2000 mg sodium) as advised by WHO (Dötsch et al., 2009).

However, consuming too much sodium chloride is closely linked to a number of negative health impacts. A known risk factor for hypertension, which raises the risk of cardiovascular disease, stroke and renal impairment, is high sodium consumption. Additionally, excessive drinking can result in fluid retention, which raises blood volume and causes edema, bloating and high blood pressure. Renal impairment may result from long-term salt overload that puts stress on the kidneys. Additionally, because it encourages calcium excretion, high salt consumption has been linked to bone demineralization and may raise the risk of osteoporosis (Taladrid et al., 2020; Dötsch et al., 2009).

Clinical and epidemiological evidence strongly supports the benefits of reducing sodium intake. Meta-analyses consistently show that lowering dietary sodium results in significant reductions in systolic and diastolic blood pressure, especially among individuals with hypertension (Dötsch et al., 2009; Taladrid et al., 2020). Substituting sodium chloride with potassium-based salts has been associated with reduced cardiovascular mortality and improved vascular function

(Farrand et al., 2019). However, salt substitutes are not risk-free. Excessive potassium intake poses risks to individuals with impaired renal function due to reduced potassium excretion capacity (Mahdi et al., 2020). Additionally, the long-term effects of chronic magnesium or calcium salt consumption remain insufficiently studied (Aronson, 2015). Thus, while salt substitutes offer promising health benefits, their use must be tailored to individual health status.

Therefore, maintaining a balanced salt intake is crucial for supporting general health and preventing chronic diseases linked to diet, even if sodium chloride is still necessary for food systems and human physiology. To reap the benefits of sodium chloride without sacrificing health, moderation and dietary knowledge are essential (Figure 1).

3. Types of salt substitutes or replacers used in food

Salt replacers, often known as salt substitutes, are substances added to food to give it a salty flavor and similar functional properties to sodium chloride (NaCl) (Kilcast & Angus, 2007). Reducing sodium intake is essential because excessive sodium consumption is strongly associated with increased risks of hypertension, cardiovascular disease, stroke and kidney dysfunction, making sodium reduction a major public health priority (Taladrid et al., 2020). In order to address the growing health risks associated with excessive salt intake, these chemicals are especially useful for creating low-sodium or sodium-reduced food compositions. Numerous artificial and natural salt substitutes have been discovered and used in a variety of food systems. The following describes the most widely used categories and examples (Figure 2).

3.1. Naturally obtained salt substitutes

Mineral sources like rocks, seas and limestone deposits are the source of

naturally occurring salt alternatives. These salts can replicate some of the sensory and functional characteristics of sodium chloride because they usually contain a mixture of ions other than sodium, such as potassium, magnesium and calcium (Table 1). The following is a list of salt alternatives that are made chemically:

3.1.1. Potassium chloride (KCl) and potassium lactate (KL)

One of the most popular and efficient alternatives to sodium chloride is potassium chloride, which may be obtained from both rock and sea salt. Due to its physiological and technological benefits, especially its capacity to lower sodium intake without significantly sacrificing sensory qualities, it is widely used in the food business. According to research, substituting potassium salts for sodium salts in the diet can effectively lower blood pressure, cardiovascular disease and hypertension (Cepanec et al., 2017). Research has revealed that when compared to items made with 100% sodium chloride, those with 70% potassium chloride and 30% sodium chloride do not significantly alter sensory perception. In this study, sensory evaluation was conducted primarily in meat products such as sausages and cured meats, where salt reduction strategies have measurable impacts on flavor, juiciness and texture (Mahdi et al., 2020). Likewise, adding potassium lactate can cut the amount of sodium chloride used by up to 30% without sacrificing the texture, antibacterial activity, or general product quality that could be obtained with larger NaCl concentrations. Potassium lactate has been evaluated mainly in fermented meat products, including salami and mortadella, where it preserves antimicrobial activity and maintains texture and water-binding capacity comparable to sodium chloride (Muchaamba et al., 2021). Applying potassium-based salts to cheese, bread,

meat products and pickled foods has proven to be successful; typically, a 50:50 ratio with sodium chloride is used to balance flavor and preservation effectiveness (Henney et al., 2010).

However, several studies have documented sensory and textural issues linked to high levels of potassium chloride substitution, such as metallic and bitter aftertastes, minor color changes and adjustments to the firmness or appearance of the product (Cepanec et al., 2017). In comparison to goods containing sodium chloride, the pH stability of those substituted with potassium lactate is essentially unaltered and does not significantly change (Horita et al., 2011). Several strategies have been investigated to cover up the harshness of potassium chloride, such as adding natural flavorings or spices that improve palatability, like chili peppers. Despite its advantages, consuming too much potassium can be harmful to one's health, especially for those with impaired kidney function. Hyperkalemia, which can be caused by elevated potassium levels, can cause cardiac arrhythmia and other potentially fatal consequences (Mahdi et al., 2020). Additionally, studies among the UK population have suggested a possible association between high potassium salt intake and weight gain in the UK population. Therefore, potassium chloride consumption should be maintained within safe limits, with a recommended daily intake ranging from 40 to 100 milliequivalents (mEq) (Farrand et al., 2019).

3.1.2. Calcium chloride (CaCl_2)

Another efficient salt alternative that can either fully or partially replace sodium chloride in food formulations is calcium chloride (CaCl_2). It is mostly derived from limestone and has both nutritional and technological benefits when used in place of potassium chloride. When taken with sufficient amounts of vitamin D, calcium chloride's capacity to

enrich food with calcium is one of the main advantages of integrating it into food systems. This helps to improve bone and dental health (Barido & Lee, 2021). Apart from its nutritional value, calcium chloride improves several food's functional and textural qualities. Research has shown that adding calcium chloride to food products, especially meat systems, improves their chewiness, hardness, softness, gelling ability and water-holding capacity (Cáceres et al., 2006). These improvements arise because Ca^{2+} ions promote ionic cross-linking between negatively charged protein groups, creating stronger gel networks and enhancing firmness and cohesiveness. The divalent nature of Ca^{2+} enhances water-holding capacity by stabilizing protein-water interactions, thereby improving moisture retention and overall structural stability in meat and other protein-based systems (Yu et al., 2022). There are numerous uses for calcium chloride in the food sector. It is used to enhance the texture and durability of meat products, pickles, cheese and canned vegetables. CaCl_2 serves as a curing and firming agent in the processing of fruits and vegetables, prolonging their shelf life and maintaining their quality by preventing the generation of ethylene and preserving structural integrity (Hou et al., 2021). Moreover, it is employed in various formulations as an anti-caking, thickening and stabilizing agent, contributing to the overall quality and uniformity of food products (Li et al., 2022).

However, there are several drawbacks to using calcium chloride in place of salt. For saltiness equivalent to sodium chloride, greater quantities are needed and it tends to produce an unwanted bitter or astringent flavor (Henney et al., 2010). Because of this sensory limitation, it cannot be used directly as a sodium chloride alternative in a variety of culinary products, including baked goods. Skin and eye irritation, gastrointestinal distress,

nausea and ulcers are among the negative health effects that can result from consuming too much calcium chloride or from handling it improperly (Norris, 1971). Due to problems with taste acceptability and possible health hazards at high intake levels, calcium chloride is still not widely used as a full salt substitute, despite being a useful functional and nutritional supplement. To ensure safety and product quality, its consumption should be maintained within the recommended daily intake range of 200-1000 mg (Carreon et al., 1981; Koopman & Pot, 1986).

3.2 Chemically synthesised salt substitutes

The taste and usefulness of sodium chloride are mimicked by chemically produced salt replacements, which also drastically lower sodium content. Usually, inorganic salts with cations like calcium, magnesium, lithium and potassium make up these alternatives. Although they can mimic some of the sensory and preservation characteristics of sodium chloride due to their chemical makeup, the particular molecule utilized determines their safety, stability and sensory acceptance (Cepanec et al., 2017). Here are a few examples of salt substitutes that are made chemically (Table 1):

3.2.1. Lithium chloride (LiCl)

Lithium chloride (LiCl), which tastes similar to sodium chloride, is one alternative salt that has been the subject of research due to the restriction of sodium chloride use in dietary applications. Lithium chloride is typically synthesized via the reaction of lithium carbonate or lithium hydroxide with hydrochloric acid, producing LiCl through a neutralization pathway. Lithium chloride was first used in commercial food formulations after early research showed that a 25% solution of the salty substance could successfully mimic sodium chloride's flavor (Hanlon et al., 1949). Lithium chloride in food products is

prohibited globally as a result of further study showing that lithium salts are extremely hazardous. Lithium ions have neurotoxic effects and can seriously disrupt the central nervous system, resulting in symptoms like disorientation and tremors and, in the worst situations, poisoning that can be fatal. According to experimental research, lithium compounds are deadly to lab animals, including rats and can seriously harm people's health if consumed or accumulated in the body. Traces of lithium are found naturally in some foods and water sources and while they are usually well-tolerated at low concentrations, excessive consumption can cause lithium toxicity, particularly in people with compromised renal function. Despite the acknowledged hazards, certain food processors have reportedly unlawfully utilized lithium salts to improve the impression of saltiness and prolong shelf life, for example, in processed meat products like meatballs (Sezer et al., 2018). Given its toxicological profile and potential for fatal outcomes, the use of lithium chloride as a food additive or salt substitute is strictly prohibited in food manufacturing and regulatory systems worldwide.

3.2.2. Magnesium chloride ($MgCl_2$) and magnesium sulphate ($MgSO_4$)

In a variety of food systems, magnesium-based salts, including magnesium sulfate ($MgSO_4$) and magnesium chloride ($MgCl_2$), have been investigated as partial substitutes for sodium chloride (Arganosa & Marriott, 1990). Their potential for substitution stems from magnesium ions' capacity to give food matrices a somewhat salty flavor while also offering certain useful advantages. To preserve acceptable sensory and technical qualities, these chemicals are typically utilized as partial alternatives rather than full replacements in formulations. It has been demonstrated that applying magnesium chloride to

meat and other protein-based foods increases cooking yield and lowers thiobarbituric acid (TBA) levels, which signify a reduction in lipid oxidation. Magnesium salts have little effect on important sensory qualities like flavor, chewiness and softness when utilized at lower doses. Moreover, the replacement of magnesium chloride or sulphate has been linked to an enhanced water-holding ability, which encourages moisture retention both before and after salting procedures (Alino et al., 2010). Magnesium salts have physiological advantages in addition to their technological uses. Frequent use of magnesium has been associated with antihypertensive action, better glucose management in those with type II diabetes mellitus and decreased systolic blood pressure. Therefore, in addition to lowering sodium, the limited use of magnesium salts in food can have nutritional benefits (Gilleran et al., 1996). These compounds have been used in various products, including fermented sausages, pickled eggs, salted cod and other meat-based products (Liu et al., 2022; Rodrigues et al., 2005). However, there are issues with quality and sensory perception when incorporating them. According to studies, magnesium salts may raise cholesterol levels and lessen the intensity of the product's color when compared to formulations based on sodium (Arganosa & Marriott, 1990). Excessive use of them can result in an unfavorable hardening of the food matrix and a harsh flavor (Liu et al., 2022). For sodium reduction, potassium chloride is therefore typically chosen over magnesium salts (Arganosa & Marriott, 1990). An excessive consumption of magnesium is harmful at the physiological level. Excessive levels might affect neuromuscular function, resulting in hypotension, heart block, nausea, muscle weakness and renal problems. Magnesium sulphate has a very high potential for toxicity, which restricts its use as a salt

alternative. Recommended daily intake varies by age: children 1-3 years require 80 mg/day, 4-8 years 130 mg/day, adolescents 9-13 years 240 mg/day and adults 270-400 mg/day, depending on sex and physiological status (Aronson, 2015). The ability of these sodium chloride substitutes to lower water activity (a_w) is critical for their preservative functionality. Potassium chloride exhibits a water-activity-lowering effect comparable to NaCl at equivalent ionic strengths, contributing to microbial inhibition (Mahdi et al., 2020). Calcium and magnesium salts also reduce a_w by binding free water through divalent cation interactions, although their effects are generally weaker than NaCl on a weight basis (Alino et al., 2010). Potassium lactate, due to its hygroscopic nature, substantially decreases a_w and maintains antimicrobial activity in fermented meat systems (Muchaamba et al., 2021). However, lithium chloride, despite its strong a_w lowering capacity, is unsuitable due to toxicity concerns (Sezer et al., 2018). Collectively, these substitutes must be dosed carefully, as their differing ionic activities modify microbial stability and shelf-life outcomes.

4. Salt enhancers and their types

Compounds known as salt enhancers are added to food formulations to increase the sense of saltiness without actually adding salt to the flavor. Usually combined with sodium chloride, they enable producers to lower the total salt level while preserving tolerable sensory qualities (Kilcast & Angus, 2007). Depending on the food matrix and the intended sensory effects, a broad variety of synthetic and natural substances can serve as salt enhancers (Figure 2).

4.1 Natural salt enhancers

Yeast extracts, hydrolyzed vegetable proteins, herbs and spices are examples of biological sources from which natural

salt enhancers are made (Table 2). These substances can help processed meals have less salt while also improving palatability and flavor complexity (Grummer et al., 2013). The following is a list of several naturally occurring salt enhancers:

4.1.1. Herbs and spices

Spices and herbs are plant-based substances with unique flavors and many health benefits. It has been established that adding them to food items is a successful way to lower sodium consumption without sacrificing or improving taste perception (Sharma et al., 2017). Herbs and spices increase the perceived intensity of salt, allowing for the use of lesser levels of sodium chloride in food products, even though they neither increase sodium absorption nor impart saltiness. By keeping a pleasing flavor and general palatability, this helps increase customer acceptability of low-sodium goods (Rosa et al., 2022a). In several culinary traditions, a range of herbs and spices, including peppermint, basil, bay leaves and rosemary, are frequently employed to intensify flavor. Research has shown that adding Mediterranean aromatic herbs to sea salt can improve salt perception, providing a useful and sensory-based method of sodium reduction (Rosa et al., 2022b). Even among people with olfactory impairment, these flavored salts are being used more and more in a variety of food preparations to enhance flavor profiles and increase gustatory satisfaction (Rosa et al., 2022a).

Nevertheless, overuse of these products can be harmful to one's health. Due to the sodium chloride in these formulations, consuming too much of them could raise blood pressure. Additionally, too much use of several herbs and spices has been linked to diseases such as stomach ulcers and hyperuricemia. To balance the safety and health benefits, the usage of herbs and spices should be moderated, even though

they are powerful natural salt enhancers (Luo et al., 2022).

4.1.2 Hydrolysed vegetable protein (HVP)

Plant-based proteins originating from sources including soy, wheat and rice bran are hydrolyzed by enzymes or acids to produce hydrolyzed vegetable proteins (HVP) (Jarunrattanasri et al., 2007). The acid hydrolysis method produces a mixture of free amino acids and peptides by treating proteins with hydrochloric acid and then neutralizing them with sodium hydroxide. By lowering the sodium level of food formulations and enhancing taste intensity, these amino acids help to improve flavor. HVPs come in a variety of forms, such as liquids, pastes and powders and their usual color range is light brown to brown (Brandsma, 2006). They are frequently used as natural flavor enhancers in soups, sauces, snacks and baked goods (Pashaei et al., 2021). One notable advantage of HVP is its glutamic acid content, which functions similarly to monosodium glutamate (MSG), allowing HVP to partially replace MSG in food products (Jeon et al., 2020).

However, those who are sensitive to or restricted by MSG should take into account that HVP also includes 10-30% residual monosodium glutamate (Scopp, 1991). Safety concerns have also been raised since the acid hydrolysis of vegetable proteins might produce potentially hazardous chemicals such as 3-monochloropropane-1,2-diol (3-MCPD), which has been linked to cancer (Brandsma, 2006). Thus, even though HVP is a natural salt enhancer that works well, its application necessitates careful consideration of target demographics, processing techniques and dose.

4.1.3. Yeast extract

Yeast extracts are frequently utilized as natural flavor enhancers, especially to increase the food products' perceived umami and saltiness. They range in hue from light yellow to dark brown and come

in powder, paste and liquid forms. Fruit drinks, soups, meat items, dairy products and baked goods are just a few of the foods that include yeast extracts (Tao et al., 2023). The abundance of glutamic acid, amino acids, peptides, nucleotides and organic acids in yeast extracts is largely responsible for their flavor-enhancing qualities. These components work together to improve taste and provide an umami feeling (Brandtsma, 2006). Thus, umami peptides, which can operate as natural substitutes for monosodium glutamate (MSG), can be obtained from yeast extracts. These peptides are generated by thermal treatment of yeast extracts at approximately 110°C, followed by purification using ultrafiltration and liquid chromatography techniques (Alim et al., 2019; Shan et al., 2022).

Despite their advantages, yeast extracts contain substances such as organic acids and nucleic acids that, if taken in excess, might cause gout and hyperuricemia (Tao et al., 2023). Therefore, even though yeast extracts are good natural salt enhancers, their use needs to be carefully monitored and managed to protect customer safety and increase flavor.

4.2. Chemical salt enhancers

Chemically generated salt enhancers are substances intended to improve a food's umami or salty perception without appreciably raising its sodium level. Monosodium glutamate (MSG), disodium inosinate (IMP) and disodium guanylate (GMP) are examples of inorganic or organic salts that are commonly used as these enhancers (Grummer et al., 2013) (Table 2). The following is a list of salt enhancers that are made chemically:

4.2.1. Monosodium glutamate (MSG)

One of the most used chemical salt enhancers in the food industry is monosodium glutamate (MSG). It is the sodium salt of glutamic acid and is found naturally in meals high in protein, or can

be made by fermenting molasses. Usually found as a colorless crystalline substance, MSG is recognized for adding a distinct umami or savory flavor that improves the overall flavor profile of food (Fernstrom, 2007). MSG is frequently used to improve the flavor complexity and palatability of processed meals, soups, sauces, snacks and particularly Chinese cuisine. Further reducing dietary sodium intake is possible by partially substituting calcium salts for the sodium component of MSG (Kilcast & Den Ridder, 2007).

Although MSG is usually thought to be safe when taken in accordance with approved dosages, excessive use has been linked to short-term negative effects such as headaches, exhaustion and weakness and in severe cases, can result in more severe neurological damage. MSG has no formal ADI, but its use is considered safe within normal dietary levels, typically 0.1-0.8% in food products (Fernstrom, 2007). As a result, following the suggested dosage levels is crucial to protecting consumers and producing the intended flavor-enhancing benefits.

4.2.2. Disodium inosinate (IMP) and disodium guanylate (GMP)

Chemically produced salt enhancers disodium inosinate (IMP) and disodium guanylate (GMP) give food a savory or umami taste, similar to that of monosodium glutamate (MSG). Since these substances are abundant in nucleotides, which intensify flavor even at low concentrations, they are especially effective. According to Rocha et al. (2020), IMP and GMP are both colorless, crystalline powders. Guanosine monophosphate (GMP) is the source of disodium guanylate, also known as disodium 5'-guanylate, while the nucleotide inosine monophosphate (IMP) is the source of disodium inosinate, also known as disodium 5'-inosinate. These two substances are frequently mixed in a 50:50 ratio to form ribonucleotides, which successfully add a savory or meaty taste at lower quantities than either one would by itself (Yang et al., 2013).

They are frequently used to improve the taste and palatability of pre-packaged foods, pasta products, instant noodles, snacks and other convenience items. Even though IMP and GMP work well as flavor enhancers, too much of them can be harmful to health, especially in young children. Sleepiness, numbness, sleeplessness and, in extreme situations, paralysis, are possible side effects. Additionally, high intake has been linked to neurological issues, respiratory issues, gastrointestinal illnesses and cardiac abnormalities (Grummer et al., 2013). Therefore, disodium guanylate and disodium inosinate are good chemical salt enhancers, but their use needs to be carefully controlled to strike a balance between consumer safety and flavor benefits.

Although these compounds contain sodium in their molecular structures, their usage levels are significantly lower than NaCl. Typically, MSG, IMP and GMP are used at concentrations of 0.1-0.5%, compared with 1-3% NaCl in conventional formulations. This results in an approximate 60-90% reduction in added salt, depending on the food matrix. Their strong umami-enhancing ability allows manufacturers to reduce total NaCl without compromising flavor intensity (Grummer et al., 2013; Fernstrom, 2007).

A comparative evaluation of the studies discussed reveals both convergence and divergence in the observed effects of sodium chloride substitutes. For instance, potassium chloride consistently shows strong sodium-replacement potential across meat, dairy and bakery systems, yet sensory acceptance varies widely, with some studies reporting minimal bitterness, whereas others note significant metallic off-flavors (Mahdi et al., 2020; Capanec et al., 2017). Similarly, calcium chloride improves gelling and water-holding capacity in meat matrices (Cáceres et al., 2006; Yu et al., 2022), but its bitterness

limits its usability in baked goods. Magnesium salts show improvement in moisture retention (Alino et al., 2010), but may negatively affect color and texture (Arganosa & Marriott, 1990). These differences likely arise from variations in food matrices, ionic strength interactions, pH environments and processing methods. Such contrasting findings underscore the need for matrix-specific optimization rather than universal substitution strategies.

Despite substantial research, important gaps persist in sodium-reduction studies. Evidence on long-term health effects of certain substitutes, such as magnesium and calcium salts, is limited and inconsistent, particularly regarding chronic consumption (Aronson, 2015). Furthermore, studies on potassium lactate remain concentrated in meat systems, with little information available for plant-based alternatives or dairy matrices (Muchaamba et al., 2021). Research on consumer sensory adaptation over time is also scarce, despite being a key determinant of successful sodium reduction (Kilcast & Den Ridder, 2007). Additionally, the synergistic interactions between natural enhancers such as herbs, umami peptides and yeast extracts remain poorly elucidated. These gaps highlight the need for longer-term, multi-matrix and cross-cultural studies.

5. Conclusions

Table salt, or sodium chloride, is an essential component of food that adds flavor, texture and preservation. However, excessive consumption of this substance is closely associated with hypertension, heart disease, stroke and other health issues. This has prompted the creation and use of salt enhancers and alternatives to lower dietary sodium levels without sacrificing food quality. This review demonstrates that multiple sodium-reduction strategies such as mineral-based salt substitutes, umami-derived

natural enhancers and chemical flavor enhancers offer promising pathways for reducing dietary sodium without compromising product quality. Salt substitutes, such as potassium chloride, potassium lactate, calcium chloride, magnesium salts and lithium salts, help reduce sodium intake without sacrificing sensory quality whereas, salt enhancers, both natural (herbs, spices, hydrolyzed vegetable proteins and yeast extracts) and chemical (monosodium glutamate, disodium inosinate and disodium guanylate), intensify the perception of saltiness. The ability of these interventions to promote public health objectives by offering tasty, heart-healthy foods to populations at risk of hypertension and cardiovascular disease makes them practically relevant. Consumers can employ herbs and natural enhancers in their home cooking and food manufacturers can use these substances to create low-sodium product lines. Comparative analysis across studies reveals consistent technological advantages for potassium and calcium salts, particularly in meat and cheese systems, although their sensory limitations necessitate partial rather than complete replacement. Umami-rich compounds such as yeast extract, HVP, MSG, IMP and GMP provide substantial flavor enhancement, enabling substantial NaCl reduction at low usage levels. Reductions in water activity achieved by potassium and lactate-based substitutes further

support their role in maintaining microbial stability. Despite progress, critical research gaps persist. Long-term safety data for several substitutes, especially magnesium and calcium salts, remain insufficient. Sensory responses vary widely across food matrices and synergistic interactions between natural enhancers, peptides and mineral salts are poorly understood. More comprehensive clinical and epidemiological evidence is also needed to evaluate the broader health implications of chronic consumption of salt substitutes. Despite these challenges, the strategic use of salt substitutes and enhancers offers a practical, evidence-based approach to reduce sodium intake, improve public health outcomes and meet the growing demand for health-conscious and flavor-rich foods. This highlights the need for continued research, innovation and regulatory guidance to maximize their nutritional, sensory and commercial potential. Overall, the most effective strategy for sodium reduction involves combining partial mineral substitution with natural or biochemical flavor enhancers to maintain palatability and functionality. Future research should prioritize matrix-specific optimization, sensory adaptation studies and mechanistic exploration of interactions among substitute compounds. Such work will support the development of safer, culturally adaptable and technologically robust low-sodium foods that align with global public health objectives.

Table 1. Salt substitutes: chemical characteristics, food applications, sensory attributes, functional properties and health considerations.

Salt Substitutes	Chemical Characteristics	Applications in Food	Sensory Attributes	Functional Properties	Health Considerations	References
Potassium chloride (KCl)	Monovalent cation, high solubility, similar ionic strength to NaCl.	Meat products, cheese, bread, and pickled foods.	Metallic/bitter taste at >30-50% substitution.	Maintains WHC, protein solubility, and reduces a_w similarly to NaCl.	Excess intake is risky for CKD patients and may cause hyperkalemia.	Cepanec et al. (2017) , Mahdi et al. (2020) and Henney et al. (2010)
Potassium lactate (KL)	Organic potassium salt, hygroscopic.	Fermented meats (salami, sausages), cured products.	Minimal bitterness improves flavor stability.	Strong a_w reduction, maintains antimicrobial activity.	High potassium risk in renal impairment.	Muchaamba et al. (2021) and Horita et al. (2011)
Calcium chloride (CaCl ₂)	Divalent cation, strong ionic cross-linker.	Meat gels, canned vegetables, pickles, and cheese.	Bitter/astringent taste at higher levels.	Enhances firmness, gel strength, and WHC via Ca ²⁺ cross-linking.	Excessive intake may cause GI irritation.	Cáceres et al. (2006) , Yu et al. (2022) and Henney et al. (2010)
Magnesium chloride (MgCl ₂)	Divalent cation, moderate solubility.	Fermented sausages, salted duck eggs, and pickles.	Bitter taste may affect color.	Enhances moisture retention, moderate a_w reduction.	Toxic at high intake, it affects neuromuscular function.	Arganosa and Marriott (1990) and Alino et al. (2010)
Magnesium sulfate (MgSO ₄)	Divalent cation with sulphate anion.	Limited use in meat and preserved products.	Bitter, slightly medicinal taste.	Improves WHC, potential hardening.	High doses may cause GI distress and hypotension.	Gilleran et al. (1996) and Aronson (2015)
Lithium chloride (LiCl)	Monovalent lithium salt, high ionic activity.	Historically studied for meat products, currently prohibited.	Saltiness similar to NaCl; toxicity prevents use.	Strong a_w depression but unsafe.	Highly toxic, neurotoxic, prohibited in food.	Hanlon et al. (1949) and Sezer et al. (2018)

Note: NaCl (Sodium Chloride), WHC (Water Holding Capacity), CKD (Chronic Kidney Disease), a_w (Water Activity), GI (Gastrointestinal).

Table 2. Salt enhancers: mechanism of action, food applications, sensory attributes and health considerations.

Salt Enhancers	Mechanism of Action	Food Applications	Sensory Attributes	Health Considerations	References
Herbs & spices	Enhance aroma-taste interaction, increase perceived saltiness.	Meat, sauces, bakery, and Mediterranean foods.	Flavor intensification, aroma complexity.	Excessive intake linked to hyperuricemia in sensitive individuals.	Rosa et al. (2022a) , Rosa et al. (2022b) and Sharma et al. (2017)
Hydrolyzed vegetable protein (HVP)	Provides umami peptides and amino acids.	Soups, sauces, snacks, baked goods.	Strong umami; slight caramel notes.	Contains residual MSG, may generate 3-monochloropropane-1,2-diol (3-MCPD).	Brandsma (2006) and Scopp (1991)
Yeast extract	High in nucleotides & umami peptides.	Soups, meat products, dairy, and snacks.	Increases savory depth.	Excess intake linked to hyperuricemia risk.	Tao et al. (2023) and Shan et al. (2022)
Monosodium glutamate (MSG)	Activates umami receptors.	Processed foods, snacks, and soups.	Enhances savory flavor.	Safe at low levels, high intake linked to headaches in sensitive individuals.	Fernstrom (2007)
Disodium inosinate (IMP)	Strong umami, synergistic with MSG.	Instant noodles, snacks, seasonings.	Meaty/savory enhancement.	Excess intake linked to neurological symptoms.	Grummer et al. (2013) and Rocha et al. (2020)
Disodium guanylate (GMP)	Strong umami, synergistic with IMP.	Soups, sauces, flavor blends.	Smooth savory finish.	Should be limited in children & gut patients.	Yang et al. (2013)

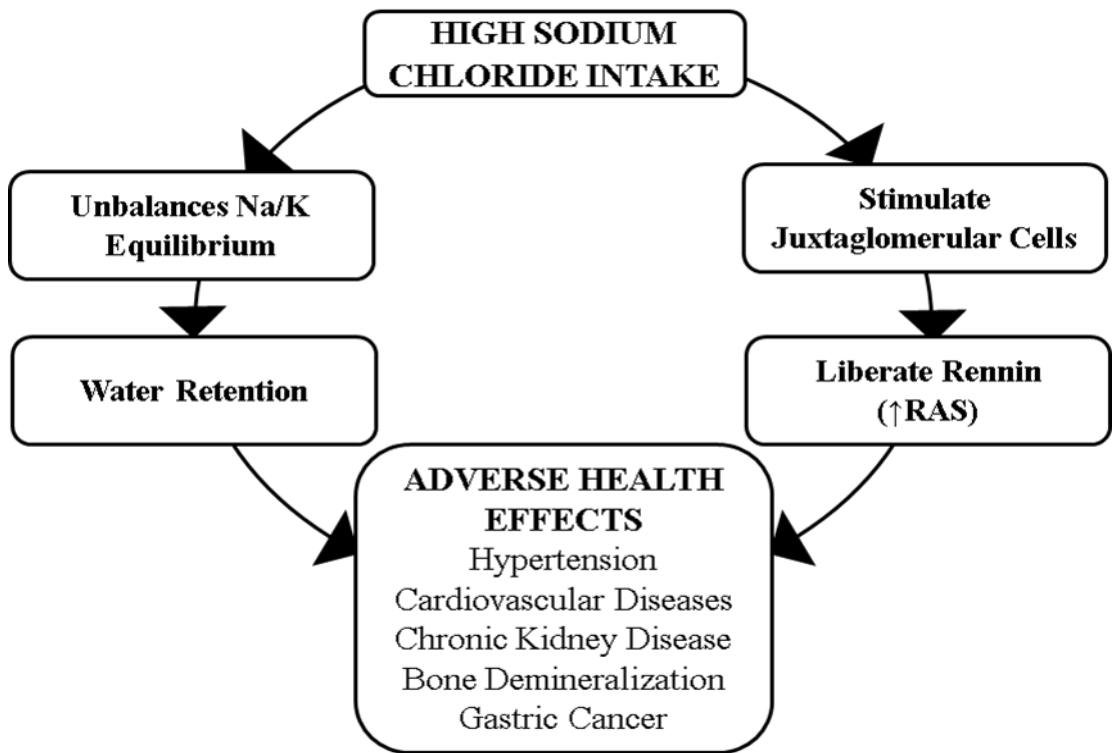


Figure 1. Schematic representation of the health effects associated with sodium chloride intake (Taladrid et al., 2020; Tsugane, 2005; Doyle & Glass, 2010).

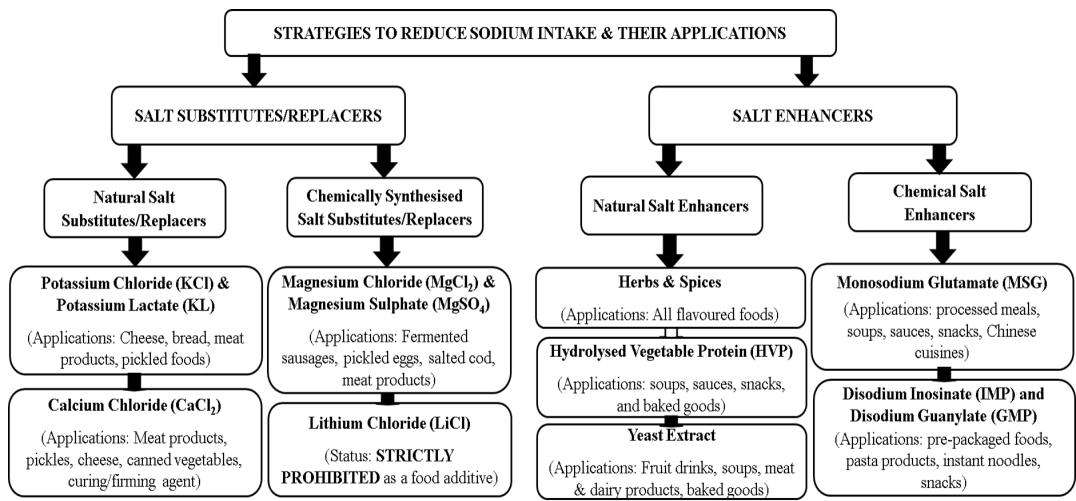


Figure 2. Strategies to reduce sodium intake and their applications.

References

- Albarracín, W., Sánchez, I. C., Grau, R., & Barat, J. M. (2011). Salt in food processing; usage and reduction: A review. *International Journal of Food Science & Technology*, 46(7), 1329–1336. <https://doi.org/10.1111/j.1365-2621.2010.02492.x>
- Alim, A., Yang, C., Song, H., Liu, Y., Zou, T., Zhang, Y., & Zhang, S. (2019). The behavior of umami components in thermally treated yeast extract. *Food Research International*, 120, 534–543. <https://doi.org/10.1016/j.foodres.2018.11.002>
- Alino, M., Grau, R., Toldrá, F., Blesa, E., Pagán, M. J., & Barat, J. M. (2010). Physicochemical properties and microbiology of dry-cured loins obtained by partial sodium replacement with potassium, calcium and magnesium. *Meat Science*, 85(3), 580–588. <https://doi.org/10.1016/j.meatsci.2010.03.009>
- Aprilia, G. H. S., & Kim, H. S. (2022). Development of strategies to manufacture low-salt meat products—a review. *Journal of Animal Science and Technology*, 64(2), 218–234. <https://doi.org/10.5187/jast.2022.e16>
- Arganosa, G. C., & Marriott, N. G. (1990). Salt substitutes in canned luncheon meat. *Journal of Muscle Foods*, 1(3), 207–216. <https://doi.org/10.1111/j.1745-4573.1990.tb00365.x>
- Aronson, J. K. (Ed.). (2015). *Meyler's side effects of drugs: The international encyclopedia of adverse drug reactions and interactions* (16th ed.). Elsevier Science.
- Barido, F. H., & Lee, S. K. (2021). Different effect of sodium chloride replacement with calcium chloride on proteolytic enzyme activities and quality characteristics of spent hen samgyetang. *Food Science of Animal Resources*, 41(5), 869–882. <https://doi.org/10.5851/kosfa.2021.e43>
- Belasco, W. J. (2008). *Food: The key concepts*. Berg Publishers.
- Brandsma, I. (2006). Reducing sodium: A European perspective. *Food Technology*, 60(3), 24–29.
- Cáceres, E., García, M. L., & Selgas, M. D. (2006). Design of a new cooked meat sausage enriched with calcium. *Meat Science*, 73(2), 368–377. <https://doi.org/10.1016/j.meatsci.2005.12.016>
- Carreon, R. E., Yano, B. L., & New, M. A. (1981). *Peladow calcium chloride (94–97%): Acute toxicological properties and industrial handling hazards* (Unpublished Dow Chemical Company report)
- Cepanec, K., Vugrinec, S., Cvetković, T., & Ranilović, J. (2017). Potassium chloride-based salt substitutes: A critical review with a focus on the patent literature. *Comprehensive Reviews in Food Science and Food Safety*, 16(5), 881–894. <https://doi.org/10.1111/1541-4337.12291>
- Clapp, J. (2020). *Food* (3rd ed.). John Wiley & Sons Ltd.
- Dötsch, M., Busch, J., Batenburg, M., Liem, G., Tareilus, E., Mueller, R., & Meijer, G. (2009). Strategies to reduce sodium consumption: A food industry perspective. *Critical Reviews in Food Science and Nutrition*, 49(10), 841–851. <https://doi.org/10.1080/10408390903044297>
- Doyle, M. E., & Glass, K. A. (2010). Sodium reduction and its effect on food safety, food quality, and human health. *Comprehensive Reviews in Food Science and Food Safety*, 9(1), 44–56. <https://doi.org/10.1111/j.1541-4337.2009.00096.x>
- Elias, M., Laranjo, M., Aguilheiro-Santos, A. C., & Potes, M. E. (2020). *The role of salt on food and human health*. In M. Çinku & S. Karabulut (Eds.), *Salt in the Earth* (Vol. 19). IntechOpen. <https://doi.org/10.5772/intechopen.86905>
- Farrand, C., MacGregor, G., Campbell, N.

- R. C., & Webster, J. (2019). Potential use of salt substitutes to reduce blood pressure. *The Journal of Clinical Hypertension*, 21(3), 350–354. <https://doi.org/10.1111/jch.13482>
- Feldman, S. R. (2000). Sodium chloride. In Kirk-Othmer Encyclopedia of Chemical Technology (pp. 1–27). John Wiley & Sons. <https://doi.org/10.1002/0471238961.1915040902051820.a01.pub2>
- Fernstrom, J. D. (2007). Health issues relating to monosodium glutamate use in the diet. In D. Kilcast & F. Angus (Eds.), *Reducing salt in foods: Practical strategies* (pp. 55–76). Woodhead Publishing. <https://doi.org/10.1533/9781845693046.1.55>
- Gilliran, G., O'Leary, M., Bartlett, W. A., Vinall, H., Jones, A. F., & Dodson, P. M. (1996). Effects of dietary sodium substitution with potassium and magnesium in hypertensive type II diabetics: A randomised blind controlled parallel study. *Journal of Human Hypertension*, 10(8), 517–521.
- Grummer, J., Bobowski, N., Karalus, M., Vickers, Z., & Schoenfuss, T. (2013). Use of potassium chloride and flavor enhancers in low sodium Cheddar cheese. *Journal of Dairy Science*, 96(3), 1401–1418. <https://doi.org/10.3168/jds.2012-6057>
- Hanlon, L. W., Romaine, M., III, Gilroy, F. J., & Deitrick, J. E. (1949). Lithium chloride as a substitute for sodium chloride in the diet: Observations on its toxicity. *Journal of the American Medical Association*, 139(11), 688–692. <https://doi.org/10.1001/jama.1949.02900280004002>
- Henney, J. E., Taylor, C. L., Boon, C. S., & Institute of Medicine (US) Committee on Strategies to Reduce Sodium Intake. (2010). *Preservation and physical property roles of sodium in foods. In Strategies to reduce sodium intake in the United States* (pp. 96–101). National Academies Press (US). <https://doi.org/10.17226/12818>
- Horita, C. N., Morgano, M. A., Celeghini, R. M. S., & Pollonio, M. A. R. (2011). Physico-chemical and sensory properties of reduced-fat mortadella prepared with blends of calcium, magnesium and potassium chloride as partial substitutes for sodium chloride. *Meat Science*, 89(4), 426–433. <https://doi.org/10.1016/j.meatsci.2011.05.010>
- Hou, Y., Li, Z., Zheng, Y., & Jin, P. (2021). Effects of CaCl₂ treatment alleviates chilling injury of loquat fruit (*Eriobotrya japonica*) by modulating ROS homeostasis. *Foods*, 10(7), 1662. <https://doi.org/10.3390/foods10071662>
- Jarunrattanasri, A., Theerakulkait, C., & Cadwallader, K. R. (2007). Aroma components of acid-hydrolyzed vegetable protein made by partial hydrolysis of rice bran protein. *Journal of Agricultural and Food Chemistry*, 55(8), 3044–3050. <https://doi.org/10.1021/jf0631474>
- Jeon, S. Y., Lee, Y. M., Kim, S. S., & Kim, K. O. (2020). Effect of added hydrolyzed vegetable proteins on consumers' response for Doenjang (Korean traditional fermented soybean paste) soup. *Food Science and Biotechnology*, 29(1), 45–53. <https://doi.org/10.1007/s10068-019-00646-0>
- Kilcast, D., & Angus, F. (Eds.). (2007). *Reducing salt in foods: Practical strategies*. Woodhead Publishing/Elsevier.
- Kilcast, D., & den Ridder, C. (2007). Sensory issues in reducing salt in food products. In *Reducing salt in foods: Practical strategies* (pp. 201–220). Woodhead Publishing/Elsevier. <https://doi.org/10.1533/9781845693046.2.201>
- Koopman, T. S. M., & Pot, T. E. (1986). Acute oral toxicity study with anhydrous calcium chloride in male rabbits (Duphar

- Report No. 56645/52/86, p. 86). Duphar.
- Li, X., Cao, C., Yuan, D., Liu, Q., & Zhao, J. (2022). Effects of the incorporation of calcium chloride on the physical and oxidative stability of filled hydrogel particles. *Foods*, 11(3), 278. <https://doi.org/10.3390/foods11030278>
- Liu, Y., Chen, J., Zou, B., Sun, Y., Zhao, Y., Duan, M., Wang, Y., Dai, R., Li, X., & Jia, F. (2022). Evaluation of the quality and flavor of salted duck eggs with partial replacement of NaCl by non-sodium metal salts. *LWT - Food Science and Technology*, 172, 114206. <https://doi.org/10.1016/j.lwt.2022.114206>
- Luo, Q., Ding, R., Chen, L., Bu, X., Xiao, M., Liu, X., Wu, Y., Xu, J., Tang, W., Qiu, J., Ding, X., & Tang, X. (2022). The association between spicy food intake and risk of hyperuricemia among Chinese adults. *Frontiers in Public Health*, 10, 919347. <https://doi.org/10.3389/fpubh.2022.919347>
- Mahdi, Z. A., Al-Khatib, A. M., & Fneich, B. N. (2020). Replacement of sodium chloride by potassium chloride in Armenian cucumber *Cucumis melo* var. *flexuosu* pickles: Sensory and microbiological evaluation. *Middle East Journal of Applied Sciences*, 10(4), 755–761. <https://doi.org/10.36632/mejas/2020.10.4.66>
- Muchaamba, F., Stoffers, H., Blase, R., von Ah, U., & Tasara, T. (2021). Potassium lactate as a strategy for sodium content reduction without compromising salt-associated antimicrobial activity in salami. *Foods*, 10(1), 114. <https://doi.org/10.3390/foods10010114>
- Norris, J. M. (1971). *Eye and skin irritation properties of LIQUIDOW liquid calcium chloride* (Unpublished Dow Chemical Company report).
- Pashaei, M., Zare, L., Khalili Sadrabad, E., Hosseini Sharif Abad, A., Mollakhalili-Meybodi, N., & Abedi, A. S. (2021). The impacts of salt reduction strategies on technological characteristics of wheat bread: A review. *Journal of Food Science and Technology*, 59(11), 4141–4151. <https://doi.org/10.1007/s13197-021-05263-6>
- Pateiro, M., Munekata, P. E. S., Cittadini, A., Domínguez, R., & Lorenzo, J. M. (2021). Metallic-based salt substitutes to reduce sodium content in meat products. *Current Opinion in Food Science*, 38, 21–31. <https://doi.org/10.1016/j.cofs.2020.10.029>
- Rocha, R. A. R., Ribeiro, M. N., Silva, G. A., Rocha, L. C. R., Pinheiro, A. C. M., Nunes, C. A., & Carneiro, J. D. D. S. (2020). Temporal profile of flavor enhancers MAG, MSG, GMP, and IMP, and their ability to enhance salty taste, in different reductions of sodium chloride. *Journal of Food Science*, 85(5), 1565–1575. <https://doi.org/10.1111/1750-3841.15121>
- Rodrigues, M. J., Ho, P., López-Caballero, M. E., Bandarra, N. M., & Nunes, M. L. (2005). Chemical, microbiological, and sensory quality of cod products salted in different brines. *Journal of Food Science*, 70(1), M1–M6. <https://doi.org/10.1111/j.1365-2621.2005.tb09039.x>
- Rosa, A., Loy, F., Pinna, I., & Masala, C. (2022a). Role of aromatic herbs and spices in salty perception of patients with hyposmia. *Nutrients*, 14(23), 4976. <https://doi.org/10.3390/nu14234976>
- Rosa, A., Pinna, I., Piras, A., Porcedda, S., & Masala, C. (2022b). Flavoring of sea salt with Mediterranean aromatic plants affects salty taste perception. *Journal of the Science of Food and Agriculture*, 102(13), 6005–6013. <https://doi.org/10.1002/jsfa.11953>
- Scopp, A. L. (1991). MSG and hydrolyzed vegetable protein induced headache: review and case studies. *Headache*:

- The Journal of Head and Face Pain*, 31(2), 107–110. <https://doi.org/10.1111/j.1526-4610.1991.hed3102107.x>
- Sezer, B., Velioglu, H. M., Bilge, G., Berkkan, A., Ozdinc, N., Tamer, U., & Boyaci, I. H. (2018). Detection and quantification of a toxic salt substitute (LiCl) by using laser induced breakdown spectroscopy (LIBS). *Meat Science*, 135, 123–128. <https://doi.org/10.1016/j.meatsci.2017.09.010>
- Shan, Y., Pu, D., Zhang, J., Zhang, L., Huang, Y., Li, P., Xiong, J., Li, K., & Zhang, Y. (2022). Decoding of the saltiness enhancement taste peptides from the yeast extract and molecular docking to the taste receptor T1R1/T1R3. *Journal of Agricultural and Food Chemistry*, 70(47), 14898–14906. <https://doi.org/10.1021/acs.jafc.2c06237>
- Sharma, M., Gupta, A., & Prasad, R. (2017). A review on herbs, spices and functional food used in diseases. *International Journal of Research & Review*, 4(1), 103–108.
- Sun, C., Zhou, X., Hu, Z., Lu, W., Zhao, Y., & Fang, Y. (2021). Food and salt structure design for salt reducing. *Innovative Food Science & Emerging Technologies*, 67, 102570. <https://doi.org/10.1016/j.ifset.2020.102570>
- Taladrid, D., Laguna, L., Bartolomé, B., & Moreno-Arribas, M. V. (2020). Plant-derived seasonings as sodium salt replacers in food. *Trends in Food Science & Technology*, 99, 194–202. <https://doi.org/10.1016/j.tifs.2020.03.002>
- Tao, Z., Yuan, H., Liu, M., Liu, Q., Zhang, S., Liu, H., Jiang, Y., Huang, D., & Wang, T. (2023). Yeast extract: Characteristics, production, applications and future perspectives. *Journal of Microbiology and Biotechnology*, 33(2), 151–166. <https://doi.org/10.4014/jmb.2207.07057>
- Tsugane, S. (2005). Salt, salted food intake, and risk of gastric cancer: Epidemiologic evidence. *Cancer Science*, 96(1), 1–6. <https://doi.org/10.1111/j.1349-7006.2005.00006.x>
- Yang, Y., Chen, Q., Shen, C., Zhang, S., Gan, Z., Hu, R., Zhao, J., & Ni, Y. (2013). Evaluation of monosodium glutamate, disodium inosinate and guanylate umami taste by an electronic tongue. *Journal of Food Engineering*, 116(3), 627–632. <https://doi.org/10.1016/j.jfoodeng.2012.12.042>
- Yu, N., Gong, H., Yuan, H., Bao, Y., & Wang, W. (2022). Effects of calcium chloride as a salt substitute on physicochemical and 3D printing properties of silver carp surimi gels. *CyTA – Journal of Food*, 20(1), 1–12. <https://doi.org/10.1080/19476337.2021.2008510>