REVIEW

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# Development of strategies to manufacture low-salt meat products – a review

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**Abstract**
Urbanization is usually followed by changes in eating habits, with a specific trend toward the consumption of ready-to-eat products, such as processed foods. Among the latter, meat products are known contributors to high dietary sodium owing to salt addition. Salt plays an essential role in maintaining the quality of meat products in terms of acceptability and safety. However, an excessive salt intake is linked to high blood pressure and cardiovascular diseases. Hence, several studies have been competing for the discovery of salt alternatives performing in a similar way as common salt. A number of replacements have been proposed to reduce salt consumption in meat products while taking into account consumer preferences. Unfortunately, these have resulted in poorer product quality, followed by new adverse effects on health. This review addresses these recent issues by illustrating some established approaches and providing insight into further challenges in developing low-salt meat products.
**Keywords:** Low-salt meat products, Meat products, Natural salt replacers, Salt alternatives, Salt reduction, Salt modifying, Low-sodium meat products



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## INTRODUCTION

Intensity of flavor and taste of food mostly impacted by its content of salt while delicacy perception come after brain activation in response to imagine the taste. Previous finding revealed that the insula, anterior cingulate cortex (ACC), and caudal orbitofrontal cortex (OFC) are the key components of network to define flavor and taste perception. Study of brain representation by salt content through functional magnetic resonance imaging (fMRI) showed that the intensity response of anterior insula activation and amygdala activation arised by the increasing of salt content. Additonally, ACC and OFC were also more active by the presence of salt [1]. High-pace lifestyle urged food industry to produce ready-to-eat product, meat products for instance [2]. Processing of meat products includes an extensive diversity of products prepared through some degree of muscle structural shift along with the application of some functional ingredients to heighten sensory quality and appearance [3]. Salt is the most commonly added ingredient in processed meat because it is beneficial for enhancing the quality of the products. Therefore, meat and derived products are recognized as the second major contribution to dietary salt (Fig. 1).

Salt contains high amounts of sodium which plays a necessary role in the transmission of nerve impulses, maintaining plasma volume and balancing acid-base equilibrium in human metabolism.

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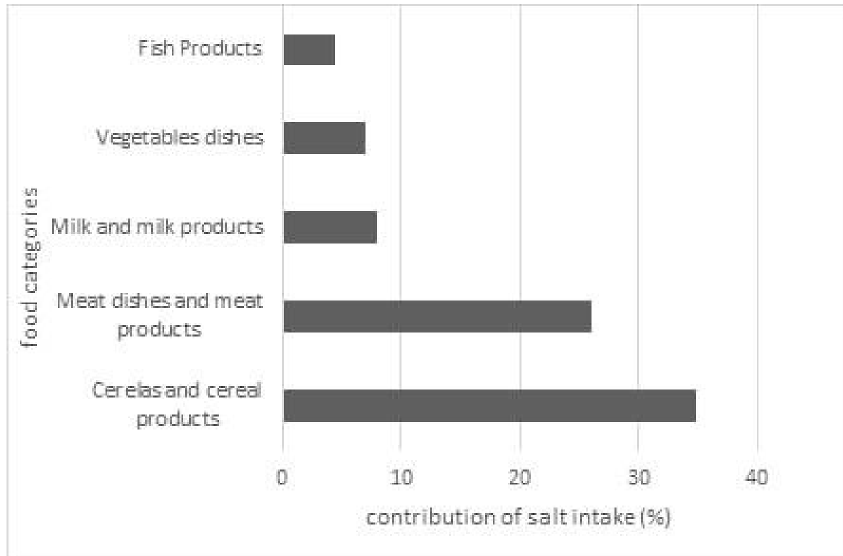


**Fig. 1. The contribution of salt intake from food categories (%).** Adapted from Verma & Banerjee [14] with permission of Taylor & Francis.

However, excessive sodium consumption is linked to harmful effects on human health such as high blood pressure which is associated to cardiovascular disease and stroke. Accordingly, recommendation of daily value (DV) is 2 g/day sodium equal to 5 g/day salt was suggested by the World Health Organization (WHO) in 2012 [4]. Based on United States Department of Agriculture (USDA) nutrition data the average consumption of salt is 10 g which exceeds the recommended DV% of sodium. Study by [5] revealed that the average consumption of processed meat is 42.7 g/day and these contribute to high daily intake of sodium (Table 1).

These common issues have furthered the development of strategies to decrease sodium content in meat products through many methods [6]. Reducing salt in meat products has been deemed one of the most impressive steps that countries can take to improve population health. Nonetheless, salt plays an important role in meat products, particularly with regard to physicochemical values [7]. The perceived saltiness is part of the characteristic taste of the meat products. A change in the

**Table 1. Sodium contents and daily value (DV, %) of processed meat and common ingredients in processed meat**

| Product (10 g) | Sodium (g) | DV (%) |
|---|---|---|
| Processed meat | | |
| Ham | 1.8 | 90 |
| Sausages | 0.09 | 4.5 |
| Frankfurters | 0.06 | 3 |
| Chicken nuggets | 0.05 | 2.5 |
| Bacon | 1.8 | 90 |
| Ingredients | | |
| Salt | 3.9 | 195 |
| Monosodium glutamate (MSG) | 1.25 | 62.5 |
| Non-fat dry milk | 0.05 | 2.5 |
| Hydrolyzed protein powder | 0.03 | 1.5 |
| Whey protein powder | 0.02 | 1 |

isoelectric point to lower pH is also caused by the adsorption of Cl– ions from NaCl to positively charged groups in myosin from myofibrils which increased the water enhancing and shape a sticky meat batter on the face thus meat pieces bind compactly during cooking hereafter improving the texture [8].

Emerging innovation schemes to reduce the salt content in meat products have been elaborated in various ways. The replacement of NaCl with other chloride salts has been an initial step. Despite these attempts, further reduction of sodium in meat processing is necessary. However, its development can have questionable effects on quality aspects such as flavor, texture, appearance, and shelf life of the products. Finally, the development of new strategies for the reduction of sodium content in processed meats remains a necessity and a challenge [6]. This review will provide insight into the consequences of reducing sodium content in meat products and the challenges in accepting the application of salt-reducing methods in meat products manufacturing, with an emphasis on public health.

## ROLES OF SALT IN MEAT PRODUCTS

Sodium chloride is one of the most important elements in meat products because it plays a pivotal role improving their quality (Fig. 2). Regarding to the palatability aspects, salt works to enhance the flavor. However, preservation and flavor are not the only motives for high levels of salt in foods.

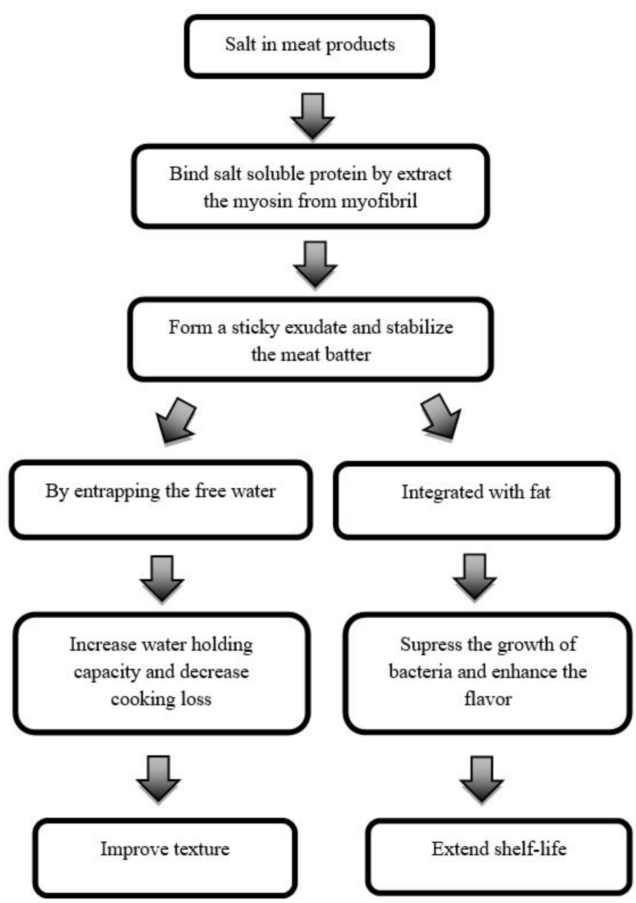


**Fig. 2.** **Salt roles in meat processing to improve the quality.**

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Sodium in salt plays a functional role in providing texture by allowing the retention of water, as well as providing gel and emulsion formation through the retraction of myofibrillar proteins, and maintaining the conditions for microbial growth. Consequently, the complete substitution of salt in meat products is not possible [9]. Accordingly, salt promotes physicochemical properties by activating salt-solubilized proteins to increase hydration, which in turn improves texture. An important step in meat processing is the extraction of myosin from myofibrils during swelling. At this time, the salt-solubilized protein forms a sticky exudate on the meat pieces, which can bind them together after cooking. In addition, for chopped and emulsified products such as sausage and bologna, this occurrence can increase the viscosity of meat batter, thereby supporting the integration of fat to form a stable meat batter that enhances the texture, flavor, and bacteriostatic properties [8].

Salt also decreases cooking loss by increasing the cohesiveness of the batter, thus increasing moisture. Cooked ham had higher cooking loss for salt levels lower than 1.4% compared with salt levels higher than 1.7% [10]. Additionally, other study revealed that NaCl is important to declined the cooking loss and enhanced the texture. It worked by increased cohesiveness of batter, improved the moisture and fat retention [11]. The shelf life of processed meat is also affected by salt levels. Reducing salt levels below those commonly used has been proven to decrease the shelf life by allowing an increase in the microbial flora growth. Hence, it is important to examine microbial activity in order to determine the exact level of NaCl that may be replaced by other ingredients [8].

Antimicrobial activity has been related to the increase in WHC: supplying ions to the media surrounding the bacterial cells causes water outflow through their semipermeable membranes. Consequently, bacteria try to manage homeostasis by activatineg ion accumulation processes or the synthesis of compatible solutes so as to maintain a suitable level of cytoplasmic water to ensure efficient functioning of all cell components. However, these processes consume significant amounts of energy and can ultimately reduce bacterial growth rates [12]. Furthermore, salt can decline water activity in foods; thus, it plays a necessary role in maintaining the growth of pathogens and organisms that cause spoilage. In summary, salt may have many important functions in improving the quality of meat products. However, the partial replacement of sodium in meat products can occur by minimizing the physicochemical aspects [13]. A study that lowering NaCl content to 1.4% and 1.7% in cooked sausages and lean meat, respectively, can be achieved without the deterioration of saltiness, firmness, water activity, and fat retention [13].

## DEVELOPMENT STRATEGIES OF SALT MODIFYING AND REPLACEMENT INGREDIENTS

The strategy of reducing salt intake is important because of the decreasing overall dietary sodium [7]. However, the production of meat products with a low sodium content is not convenient. Because common salt plays important roles in meat products, the functional properties that it provides must be considered; they cannot be reduced or replaced without considering the consequences on product quality. Normal salt products are typically used as benchmarks for the development of low-sodium meat products. Furthermore, the same quality parameters must apply to low-salt meat products as those valid for products containing common salt [14]. Currently, there are some ingredients that contribute to the reduction of sodium in food processing (Table 2).

### Salt modifying

Changing of salt physical characteristic is one of the main strategies to reduce salt intake beside partial replacement of salt by salt replacers. Sodium is sensed while the moment of sodium concentration in saliva higher than saliva concentration itself, in biref when it overstep residual

**Table 2. Toward research development of salt replacers ingredients to reduce sodium in food sector**

| Sodium replacer ingredients | Target | Result on products | References |
|---|---|---|---|
| Mineral salt | | | |
| KCl | Evaluated effects on the characteristics of meat products | Increased cooking loss affected the sensory. But it has similar characteristics as salt. | [72] |
| $MgCl_2$ | Examined effects of the flavor | Produced off-flavors (bitter, metallic, soapy) | [73] |
| $CaCl_2$ | Reducing water activity for stability during storage time | Significantly increased water activity | [72] |
| K-Lactate | Examined effect of substitution on sensory parameters | Decreased cohesiveness and saltiness at 40% substitution | [28] |
| Salt mixture | | | |
| Pansalt® | To know the effectiveness of PanSalt® as a commercialized salt replacer on quality characteristic | Negative effects on technological and sensory properties | [30] |
| $KCl:CaCl_2$ | Evaluated effects on the characteristics of meat products | Increased cooking loss and protein denaturation | [72] |
| $KCl:MgCl_2:CaCl_2$ | Reduce sodium in meat products with mixture of chloride salt | Lower sodium contents but increased potassium and calcium amounts | [74] |
| KCl:Glycine | Examined substitution of salt levels on sensory quality | KCl mask sweet taste from glycine but can not substitute salty taste from NaCl | [28] |
| Flavour enhancers | | | |
| Savoury powder (SP) | Determined the impact of low-salt formulations on the functionality | Did not provide sufficient ionic strength to adequately extract myofibrillar proteins. | [59] |
| Monosodium glutamate (MSG) | Investigated effect MSG on saltiness and sodium reduction | Sodium concentrations can be reduced until 0.3% without negative effects on acceptance by the addition of MSG. | [75] |
| Lysine, disodium guanylate, and disodium inosinate | Assessed effects of adding lysine, disodium guanylate, and disodium inosinate on the physicochemical low sodium products | There is no different in any attribute of the sensory analysis compare the content of NaCl | [35] |
| Natural replacers | | | |
| Winter mushroom powder (WMP) | Evaluated the quality characteristics of low-salt products manufactured with the addition of WMP | Texture was softened and it can inhibit the lipid oxidation | [42] |
| AlgySalt® | Reduced the used of NaCl and its effects and characteristics | Gave harder texture | [74] |
| *Salicornia herbacea* L. | Determined the effects on the textural properties | Similar textural properties to those of product contained NaCl | [37] |
| *Suaeda maritima* | Developed appropriate commercial seablite products as salt marsh plants | Give salty taste and can reduce the use of salt | [76] |

concentration from a previous stimulus. Some of alternative salts are less effective due to not able to replicate the specificity ion channels of salts. Therefore, address physical salt modifying as strategy to reduce salt content in food is promising. Speculation that sodium acceptance in mouthfeels are depends either in oral processing or effective delivery. Effective delivery is dependent on two factors which are the dissolution of salt from its crystal form and the diffusion of free sodium through the static saliva barrier layer on the surface of the tongue. As the static diffusion cannot be impacted, the left factor is dissolution from crystal to liquid form and one path to control which would be through the reduction of crystal size based on an increase in the surface area [15,16].

Smaller crystals of salt could give a faster delivery of sodium into the saliva, affected the maximum sensed of saltiness. Preveious study revealed that perception of salty taste is highly related to the physical shape of salt and therefore, modification of salt crystal size could be a feasible approach to reduce sodium content. The employement of small sea salt particles with 20 microns showed higher salt diffusion into the food matrix, consequently it exhibit higher perception of saltiness [17]. Salt microspheres brand as Soda-Lo® made by free-flowing cystalline micospheres and applied as salt replacers. By this physical formation salt deliver a saltier taste by maximizing

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the surface area relative to volume and claimed reduce the salt content in product up to 20%–50% [18]. Addition of coarse-grained salt with crystal size: 0.4–1.4 mm led to an increment of salty through taste contrast and an accelerated sodium delivery measured in the mouth and in a model mastication simulator. Thereby, the utilization of aqueous salt solution to the samples also increased saltiness perception through faster sodium availability came to a greater contrast in sodium concentration. These strategies revealed a sodium reduction of up to 25% while maintaining taste quality [18,19].

## Salt replacements

The development of strategies for the production of low-salt foods, in particular meat products, with ingredients replicating the different roles of salt has been conducted in various studies as mentioned above. Thus, a good strategy to improve consumer acceptance relies on the use of ingredients as salt substitutes. The discussion below will describe in detail the different types of ingredients used to reduce sodium in meat products.

### *Mineral salt*

The partial substitution of classic salt with other mineral salts has been intended to reduce the sodium content in meat products. Potassium, calcium, and magnesium chlorides have been used to stabilize meat emulsions in low-sodium meat products. This has demonstrated that potassium chloride (KCl) and NaCl at similar ionic strengths interact with meat proteins in similar ways, while $CaCl_2$ and $MgCl_2$ have shown the opposite behavior [20]. Furthermore, the utilization of a mixture of 1% NaCl, 0.5% KCl, and 0.5% $MgCl_2$ in mortadella, employed to partially reduce sodium, provided the best emulsion stability, although it exhibited poor flavor [21]. Thus, reformulating low-salt meat batters is challenging because it requires other ionic compounds to replicate the water-retention, protein, and fat binding functions of the sodium chloride that is removed [13].

KCl is the most commonly used salt replacement in food among chloride salts. Partial substitution of sodium chloride with KCl in cooked pork ham is a viable strategy to produce healthier low-sodium products. However, the result exhibited lower lightness (L*) and higher bitterness, whereas redness (a*), yellowness (b*), and overall sensory parameters were not distinct among the treatments [13]. Indeed, significant drawbacks such as increased bitterness and loss of saltiness are found in a 1:1 mixture of sodium and KCl in solution [8]. The Food Safety Authority of Ireland (FSAI) has declared that salt replacement with KCl could not be applied associated with high consumption of potassium is not tolerated by group of populations with some illness such as diabetes, kidney failure, and cardiovascular disease [22]. Otherwise, KCl has similar antimicrobial effects as NaCl as evidenced by tests with pathogenic bacteria, such as *Aeromonas hydrophila*, *Enterobacter sakazakii*, and *Shigella flexneri*; this property is necessary to ensure adequate product shelf life [23].

Another chloride salt that was used to substitute sodium chloride is lithium. Sodium and lithium are principal cations that have a salty taste. Consequently, lithium is unremarkably used to replace sodium in meat products because it almost perfectly replicates the saltiness of sodium. However, lithium chloride appears to be considerably toxic to the human body [7,14]. Another research conducted to provide a potential rapid method for detecting the amount of lithium in meatballs when it was used to replace sodium. They assumed that food naturally contains lithium in concentrations that can be tolerated, whereas high amounts have toxic effects on living organisms. Therefore, the quantification of the lithium chloride in food products is important because of its critical impact on human health [24]. According to these statements, the outcome of a previous study supports that lithium chloride at 526–840 mg/kg body weight is lethal to rats, while the concentration of 5 g/kg body weight leads to fatal poisoning in humans [25]. Research have been done by diffusion of magnesium in muscle foods in order to reduce the salt content in dry-cured hams. Partial replacement of NaCl with $MgCl_2$ was observed and exhibited higher water activity inside the product for the same amount of total added salt. This could be explained because Mg has higher charge density (0.082 units of charge/molecular weight) than Na (0.044 unts of charge/ molecular weight) which impacted to higher difficulty of Mg for penetrating inside to dry-cured ham. Simultaneously, $Mg^{2+}$ cations bind strongly to the protein polar groups, reinforce protein interaction thus prevent the penetration of salt [26].

Studies on sausages with salt substitution by K-lactate and Na-diacetate were conducted to investigate their relevance for consumer acceptance. These samples were formulated with 0.5% NaCl and 1.5% K-lactate/Na-diacetate replacement, which improved the flavor significantly albeit gave a harder and less juicy texture [27]. The textural change was also indicated in previous research on fermented sausages containing lactate as salt replacers. The replacement of salt by more than 30% by K-lactate showed a different texture due to lower cohesiveness [28]. Concerning microbial growth, potassium, sodium, and calcium lactates have similar effects as common salt. In addition, the combination of potassium lactate and sodium diacetate reduced sodium levels by 40% and extended the shelf life by containing the growth of bacteria in packaged meat products [29]. Ultimately, other mineral compounds can replace salt and determine low sodium levels in processed foods, especially meat. However, it is important to take into account the processing of meat products and the successive actions that are carried out to obtain the same properties as those promoted by salt. Moreover, they may have adverse effects on human health.

### *Salt mixture and flavor enhancer*

Mixture of salts have been used for the reduction of sodium in processed meat products offered to consumers in sensory tests, and some of those performed satisfactorily, showing similar perceived saltiness [20]. Pansalt® is a commercial trademark of a mineral salt mixture containing KCl, magnesium sulfate, and the essential amino acid L-lysine hydrochloride, which can reduce sodium by nearly half. It did not exhibit organoleptic issues during the sensory triangle test. Contrarily, it performed poorly regarding to cooking loss value yet had a similar appearance with ground beef patties formulated with common salt [30]. In addition, Pansalt® is revealed has the same taste as common table salt [31]. Nevertheless, owing to its high potassium content, subsequent epidemiological studies have shown that it may protect against the development of hypertension [32]. As mentioned before, high consumption of potassium can also affect health negatively, such as in kidney failure. KcLeanTM salt and Sub4salt are other commercial salts that are used frequently to reduce sodium in meat products. KcLeanTM salt combines a natural proprietary ingredient with NaCl, and KCl. Subsequently, Sub4salt consists of sodium gluconate, NaCl, and KCl. They both act to reduce sodium up to 50% and 35%, respectively [31]. Manufacturing test using salt and Sub4salt as curing agents showed no differences in flavor, texture, and color. Furthermore, in case of product safety and stability both showed same ability to control microbial, pH, and water activity [6]. Subsequently, the application of a salt mixture Morton Lite Salt® and its effect on ham bacon and turkey ham was evaluated. According to this purpose, it recorded that the same flavor was preserved as with salt control, and that protein hydration was retained in meat products [8].

Another study conducted a partial substitution of NaCl with a blend of KCl/glycine and K-lactate/glycine in fermented sausage. Partial replacement was allowed until the substitution of NaCl reached 40%–70% and resulted in significant flavor and textural defects [28]. In lacón, a conventionally processed meat product from northwest Spain made from pork forefoot salty marinated, dried, and aged. It found no notable distinction in the total microbial count when NaCl

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was substituted by a blend of 45% NaCl, 25% KCl, 20% $CaCl_2$, and 10% $MgCl_2$ as compared to the control (100% NaCl). $CaCl_2$ worked as an inhibitor of the growth of mesophilic aerobic bacteria and replicated the function of NaCl. Conversely, with respect to the amounts of halotolerant bacteria, a significantly higher cell count was observed in these mixtures. Previous research has demonstrated that NaCl inhibits the evolution of salt-tolerant bacteria, lactic acid bacteria, and pathogenic bacteria [33]. Simultaneously, the analysis of partial substitution of NaCl with mixtures of NaCl, KCl, and $MgCl_2$ with a focus on quality revealed the presence of chloride salt mixtures significantly reduced water retention, elasticity, and gel strength of myofibril protein when the replacement rate was higher than 50%. Otherwise, they reported lower oxidation to increase myofibril carbonyl content and simple sulfhydryl oxidation via denaturation. These processes also support the presence of amino acids presenting hydrocarbon side chain groups in the hydrophobic central core, which denoted appreciable features owing to the compact pore structure [34].

Flavor enhancers also enter the market and are frequently used to substitute salt fully or partially in meat products. The production of frankfurter by replacing salt with 50% and 75% KCl and adding monosodium glutamate (MSG), lysine, and taurine as flavor enhancers resulted in an unpalatable flavor. In addition, Provesta® and Aromild® are products of yeast autolysates that can cover the bitter flavor of KCl and reduce NaCl [8,35]. Indeed, while using flavor enhancers health concern should be consider and also the defection of the products. In addition, MSG has been connected with possible health implications as well as hyperactivity, sickness, and migraines. Furthermore, autolysates have a strong broth flavor, which may not be appreciated in some products [31].

### *Natural replacers*

A high intake of sodium is particularly associated with hypertension and other cardiovascular diseases, which encouraged many researchers to develop salt alternatives from other mineral compounds, as described above. However, the safety of several synthetic compounds as salt substitutes is questionable. This has prompted the research for salt substitutes from natural ingredients. The use of natural ingredients is more efficient and effective. In addition to being affordable, these ingredients also inspire trust by promoting additional beneficial health effects on health. In this framework, a detailed discussion will follow regarding salt alternatives that have been applied to meat products and candidates that are considered to reduce salt from natural sources.

### *Halophytes*

Halophytes are plants that can potentially reduce salt because of their characteristics, morphology, and ability to survive in highly saline environments. Glasswort (*Salicornia herbacea* L.) is a halophyte that grows in salt marshes. It is affordable and has been utilized as a salt substitute in many food types. Dry-cured ham products are some of the meat products obtained with glasswort powder, which reduced salt content by 50%, as well as providing color, texture, and sensory properties. However, a perspective on shelf-life stability is still needed in future studies [36]. In terms of color change, the addition of glasswort minimizes the alteration and is effective in reducing salt in cooked sausages owing to the salt and dietary fiber contained in them. Furthermore, it also stabilized the emulsion and improved the texture [37]. The ability of glasswort to reduce salt in meat products is associated with its tolerance to salinity up to 3% NaCl concentration and the ability to accumulate salt from soil [38]. In addition to minimizing the risk of drawbacks, it can also act as an antioxidant. Isolated antioxidant compounds, such as dicaffeoylquinic acid and flavonol glucosides, from *Salicornia herbacea* L. The results showed that dicaffeoylquinic acid derivatives such as 3,5-dicaffeoylquinic acid, 3-caffeoyl-4-dihydrocaffeoylquinic acid, methyl 3,5-dicaffeoyl quinate, 3,4-dicaffeoylquinic acid, and methyl 4-caffeoyl-3-dihydrocaffeoyl quinate prevented the formation of cholesteryl ester hydroperoxide through copper ion-induced rat blood plasma oxidation. Similar activity was observed for the two flavonol glycosides, isoquercitrin 6-O-methyloxalate and quercetin 3-O-β-D-glucopyranoside [39].

Because of the recent significant increase in the consumption of halophytes as healthy foods, the impact of mineral concentration in *Salicornia ramosissima* has been evaluated. The results indicated that the concentration of sodium increased simultaneously with increasing salinity [40]. Moreover, the effects of salinity on the germination of *Kochia scoparia* under greenhouse conditions were observed. This showed that higher salinity determined a higher concentration of sodium in its shoots and roots [41]. Nevertheless, the development of new approaches to low-sodium meat products using halophytes is still needed. There is still a lack of information regarding the execution and efficacy of these ingredients in reducing salt levels in meat products and whether they have positive effects on human digestion.

### Natural seasonings, herbs and spices

Research used winter mushroom powder (WMP) as a seasoning salt substitute in chicken nuggets indicated that WMP has no negative effects on sensory properties. Hence, further studies on natural salt replacements and possible useful effects on health, such as antimicrobial and antioxidant activities [42]. On the contrary, it was demonstrated the possibility of reducing NaCl using naturally brewed soy sauce while focusing on not sacrificing the consumer's acceptance of stir-fried pork. Appropriately, it was possible to replace salt with brewed soy sauce between 50%, 17%, and 29%, respectively, without significant effect on flavor and delicacy [43]. Another study investigated red wine pomace seasoning (RWPS), extracted from wine pomace as a natural seasoning for salt replacement. This also works as an antioxidant and antimicrobial that is beneficial in food manufacturing while presenting fiber, phenolic compounds, and particular minerals such as potassium. The use of RWPS enabled the reduction of salt content in beef patties and postponed microbial activities, such as the growth of aerobic mesophilic and lactic bacteria [44]. Oregano and rosemary have been also indicated as salt alternative seasonings. In addition to having the ability to reduce salt, they also contain high concentrations of compounds that counteract free radicals such as flavonoids, phenolic acids, and terpenes. The addition of oregano to manufactured food was tested among normotensive and hypertensive consumers. Supplementation with oregano shifted the preference for lower-salt foods and can be suggested for the treatment of hypertensive consumers. In addition, a study proved that rosemary can replace approximately 48% salt and has a positive correlation with taste acceptability [45,46].

Garlic (*Allium sativum* L.) is a herb that has been used as a good alternative to reduce salt in many types of food because of its affordability. The bioactive components in garlic and their potential role in health maintenance have gained popularity as salt substitutes to prevent various diseases. The most beneficial aspects of garlic are its antimicrobial, anticancer, antioxidant, immune boosting, and antidiabetic activities. In addition, it plays a role in the prevention of cardiovascular diseases [47]. In Brazilian frankfurters, the addition of fresh garlic decreases the sodium content, simultaneously retards lipid oxidation, and promotes microbiological stability, which means that it works as an antimicrobial agent. Moreover, it has been suggested that garlic derivatives can be used for manufactured goods without loss of acceptability [48]. The treatment of rabbit meat burgers with garlic powder showed that it was not adequate to significantly reduce the decrease in nutritional value determined by salt addition, which is caused by oxidation, although the sodium content was lower. However, increasing the concentration of garlic was suggested in a further study [49]. Coriander (*Coriandrum sativum* L.) seeds, leaves, and roots are edible and possess a particular flavor; consequently, they are commonly used for seasoning purposes. In addition to its ability to prolong

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the shelf life of foods, coriander is an herb that contains sodium in its leaves and seeds. Coriander in food usually exhibits activity as a balancing hormone beside its anti-oxidant, anti-diabetic, anti-mutagenic, antianxiety, and antimicrobial properties [50]. The addition of coriander together with garlic in smoked hilsa fish lowered the salt and fat contents, yet brought less moisture [51]. As mentioned above, coriander essential oil isolated from coriander seeds has been shown to exhibit significant antioxidant and antimicrobial activity in pork sausages and enhance their quality [52].

Spices such as chili, black pepper, and mustard are used ubiquitously in Asian dishes and provide sweet, sour, bitter, salty, and umami tastes [53]. In particular, evaluation of the addition of capsaicin, the spicy component in chili pepper, by comparing it to an NaCl solution, and recorded a significant salty taste from testing approximately 20 participants [54]. Notwithstanding, the salt flavor presented by hot spices in food has not been specifically clarified, yet revealed that capsaicin influenced the insula and OFC metabolic activity by modifying the neural pathways owing to its salty taste, and consequently promoted lower preference for salt, daily salt intake, and blood pressure [55]. Bologna sausages were found healthier while the sodium content was lowered to 50% NaCl. It was replaced by KCl and a mixture of herbs and spices (coriander, Jamaican pepper, onion, cardamom, and white pepper) without negatively affecting safety and palatability. The combined actions of herbs and spices could counterbalance the drawbacks resulting from the use of KCl by covering the bitter taste, and helped to achieve better taste while providing lower sodium levels in meat products [56]. Moreover, the use of herbs, spices, and whey proteins as natural salt replacements worked well in ready-to-eat foods, particularly chicken supreme: they reduced the sodium and salt content by almost 50% without any drawbacks [46].

## ALTERNATIVE PROCESSING METHODS

In addition to using salt replacers to reduce sodium in meat products, alternative methods need to be developed, particularly in the processing aspects. Green technologies such as high-pressure processing (HPP), ultrasounds (US), and pulsed electric field (PEF), as non-thermal processing technologies in the food industry, have the ability to reduce the additive content in meat products, especially NaCl. They work by modifying protein structure and boosting functional quality while reducing salt. They will be discussed in more detail below.

### High-pressure processing

Among technologies that have a high potential for manufacturing meat products, one is HPP [46]. Fundamentally, HPP is characterized by a hydrostatic pressure of approximately 100–800 MPa which is applied at a certain temperature and for a certain duration. It works by changing the structure of foods to inactivate unwanted microorganisms, thereby contributing to reduce the salt. Several studies have been conducted to investigate the interaction between salt content and high-pressure treatment in the functional properties of meat products [57]. High-pressure treatment enhanced the stability of emulsions and reduced cooking loss compared to control sausages [58]. However, an increase in cooking loss was observed when salt was reduced below 2.0%. Furthermore, salt content of cooked ham decreased to 45% (1.1% NaCl by substitution with 0.25% phosphate and 1.1% KCl) with HPP 100 MPa It is technologically suitable in terms of water holding, consistency, and appearance. In another study, HPP at 600 MPa (3 min, 8℃) was used to reduce sodium in nitrite-free sausage, and an increase in shelf-life was reported without negatively affecting the sensory aspects; also, the high water holding capacity caused the texture to become softer and less elastic [59]. Further study provided evidence that HPP can maintain cooking loss, in addition to lowering the salt content. HPP treatment of meat emulsion products resulted in lower cooking loss because of a higher viscoelastic network and retained the color performance, especially at 200 MPa. Use of this method is supported by sensory, texture, and color evaluation, as well as scanning electron microscopy analysis. In conclusion, HPP treatment can be used to lower the salt content in meat products, and by proper selection of processing variables such as pressure, time, and temperature, it also has the potential to maintain cooking loss [60].

### Power ultrasounds

US are one of the most effective methods to reduce salt in food. Essentially, they produce vibrational energy from sound waves [61]. In this way, mass transfer process and modification of the cell membrane occur when US are applied for salt reduction. This method has helped in the processes of curing, marinating, drying, and tenderizing tissues during meat processing. In addition, it leads to better salt allocation in the meat and simultaneously delivers a higher salt flavor, although the overall NaCl concentration is reduced [62]. The interplay between water and protein during pork salting by power US application. This indicates that US can expedite mass transfer and support protein outlay, while allowing for faster NaCl assimilation by microjetting: this can be considered as a microscale inoculation system that interacts with the interface layer [63]. The application of US in restructured cooked ham with different concentrations of salt to evaluate the physicochemical parameters, microstructure, and sensory aspects. US were applied at 600 $W/cm^2$ for 10 min with four different concentrations of salt to reduce its concentration. The treatment with 0.75% NaCl could achieve a 30% reduction of salt without compromising quality [64]. Furthermore, in the cured ham, the application of US allowed reaching a 2.25% level of NaCl at 72 $W/cm^2$ for 2 h, with no effect on quality attributes [65]. The replacement of 50% NaCl using US at 600 $W/cm^2$ and 20 kHz for 10 min, which showed an improvement in NaCl diffusion and decreased cooking loss during storage. Thus, this result is in agreement with other studies by showing that US can help reduce sodium levels in meat products while improving quality [64].

### Pulsed electric field

PEF is another of the non-thermal technologies that can improve food quality while reducing salt content. Recently, some studies showed that PEF influences saltiness by enhancing the diffusion of salt and generation of salty taste. However, PEF treatments, despite being very promising in reducing salt in many ways, spoiled the salty taste [66]. In particular, the research carried out showed that processes in PEF technology prompted the absorption of more salt owing to the interference with cellular tissues and the effects of mass transfer. In brief, PEF can reduce the concentration of salt and the duration of the process due to an improvement in uptake rates [67]. Beef meat treated with PEF determined improvements in salt diffusion and perception of released sodium during chewing, resulting in saltiness. Indeed, the salt content was synchronously subtracted without impairing sensory aspects, lipid oxidation, or microbial stability. In addition, PEF significantly enhanced salt diffusion during the curing steps of fresh pork; otherwise, it has a narrow role in meat safety [50].

In summary, novel green technologies, such as HPP, power US, and PEF, are available to help develop technologies to reduce the salt content in meat products. As non-thermal technologies, they have proven their ability to reduce the salt content by affecting several parts of the process, such as the diffusion of salt and natural detachment of sodium. Consequently, these methods can be considered as novel approaches to reduce sodium levels in processed meat while maintaining other quality parameters. The discussion of the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses are needed. The findings and their implications should be discussed in the broadest context possible. Future research directions may


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also be highlighted.

## FURTHER CHALLENGE IN LOW-SODIUM MEAT PRODUCTS

Various strategies to reduce the consumption of sodium from meat products have already been developed to address current health issues. Sodium decrement is currently a topic of international interest that has been intensely discussed. WHO arranged a forum and technical meeting to review and discuss the connection between high salt intake and health as part of Global Strategy on Dietary, Physical Activity and Health [68]. A direct decrease in salt levels in meat products must be followed by the addition of other ingredients or treatments [6]. However, the reduction of sodium is still challenging especially with regard to consumer acceptance. Some studies have found that the replacement of salt in meat products resulted in deterioration of the quality of meat products, particularly flavor and texture, which are the most important parts of customer acceptance. On the contrary, replacing salt with other synthetic compounds could have other negative effects on health. The main implementations for salt reduction are food redevelopment and consumer education and training [69]. It concluded that consumer education is the most challenging task in the development of low-sodium meat products. Concerning the connection between salt consumption and health, government agencies and organizations need to continue educating consumers to become more aware [8]. Moreover, consumers' preferences should be consider; for instance, natural food additives and concerns regarding the safety of synthetic preservatives have prompted the food industry to research natural alternatives. Indeed, natural ingredients also have other positive influences on human health, such as antioxidants and antimicrobials [70]. Accordingly, it will be particularly challenging to perform studies on the alteration of the quality of meat products by additional natural salt replacers. Consequently, consumers should be educated to become used to consuming low-sodium meat products with minimal adjustments.

According to the research and development technology meat industry need to offer remarkable quality raw materials and engage through marketing strategies. For instance, the food ingredient industry must collaborate with pharmaceutical to determine novel healthy ingredients from natural derivatives to find suitable salt replacers for use in meat products by regard to the quality and acceptability. High of scientific proof must also be available to support the health enhancing properties, for which the co-operation of universities and research bodies is necessary. Although, a lot of meat products by now have a relatively healthy aspect and reflect the outstanding potency for delivery of healthy ingredients. Those steps will allow meat producers to gain access to enhance functional food markets [71].

## CONCLUSION

This review highlights recent approaches and strategies for salt reduction to provide insight and respond to issues related to the positive correlation between excessive consumption of salt and the drawbacks for human health, especially cardiovascular diseases. Accordingly, several leading studies have been conducted to develop low-salt meat products and a number of challenges have been addressed to maintain acceptability and quality aspects in the development of low-salt meat products. At the same time, some approaches have led to the discovery of new side effects on health upon the replacement of salt with alternatives.

These issues bring further challenges for recreating salt alternatives to establish low-salt products that can meet customer preferences. A parallel strategy should work by providing consumer education about the necessity of using lower salt concentrations in ready-to-eat products.

Nowadays, natural ingredients are in great demand because of their health benefits. Therefore, identifying natural ingredients as salt alternatives while discovering their positive effects on health can possibly support this dietary change and lay grounds for further research in the future.

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