

# Effect of reducing sodium chloride based on the sensory properties of meat products and the improvement strategies employed: a review

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## Abstract

Many consumers are concerned about the high levels of salt intake owing to the accompanied risk of chronic diseases. Due to this dietary concern, the food industry has recommended the reduction of salt content in many products. However, the addition of salt to meat products improves their quality and sensory properties, including saltiness, color, juiciness, and texture. Because quality deteriorations could induce decreased sensory scores owing to salt reductions, the challenges involved in improving the quality of reduced-salt meat products have been addressed. During the development of low-salt meat products, it is important to reduce sodium content and address the problems that arise with this reduction. Modified salt, organic acids, amino acids, nucleotides, hydrocolloids, high-pressure, ultrasound, electric pulsed field, and irradiation have been suggested as strategies to replace or reduce sodium content, and sensory scores could be improved by these strategies. Therefore, when developing a low-salt meat product, several perspectives must be considered and the latest technologies that could resolve this problem should be adopted.

**Keywords:** Salt, Shelf life, Water holding capacity, Emulsion stability, Reduced-salt, Meat product

## INTRODUCTION

In developed countries, the recommendations and suggestions for salt intake via food consumption are based on scientific research results [1]. Various scientific studies have shown that salt is an essential ingredient in food; however, reduced salt intake is also recommended. High salt intake is known to increase the risk of chronic diseases, including stroke, hypertension, and cardiovascular diseases. However, salt is a vital component for maintaining human life as it helps to maintain adequate water balance in the body. Therefore, consuming an appropriate amount of salt is essential for the maintenance of good health [2].

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### Authors' contributions

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The role of salt in food processing is important. In fact, salt plays a central role in enhancing food properties and for food preservation. Salt is well known to be important for meat processing. Salt's role in meat processing is to form the desired texture by extracting myofibrillar proteins. Myofibrillar proteins contribute to the water holding capacity (WHC) and emulsion stability [3,4]. Thus, the addition of salt is an important process when manufacturing meat products to sufficiently elute the salt soluble myofibrillar proteins. Another role of salt in meat products is to enhance flavor and juiciness. Salt also inhibits the growth of microorganisms during storage. The antimicrobial effect of salt is well known and has an important impact on the role of salt in various foods [5]. In addition, the flavor of meat products can be enhanced by the addition of salt ingredients. Related with aforementioned role of salt in meat products, attractive textural properties, juiciness, flavor, and safety shelf-life of meat products could be achieved. Although salt is the most important additive in the manufacturing of meat products, meat industry has tried to reduce or replace salt in meat products with salt reduction targeting campaign [1]. As a result, there are obvious limitations in processing meat products without the addition of salt.

This review provides an overview of current studies that aim to assess the role of salt in meat processing technology to aid in the development of technologies that can reduce or replace salt in various meat products focused on sensory evaluation.

## THE CHALLENGES OF SALT REDUCTION

As previously stated, salt plays various roles in food; it can inhibit microorganism growth, enhance flavor, and improve texture. However, for the reasons highlighted below, the sodium chloride content in our dishes must be reduced or replaced with alternatives.

## IMPACT OF NaCl ON HEALTH AND CONSUMER BEHAVIOR

The word salt is derived from the Latin words, *salus* and *salubris*, meaning health and healthy, respectively. Indeed, adequate salt intake is an essential requirement for maintaining good health in humans owing to its multiple physiological roles [6]. Sodium is an important nutrient that controls the volume of extracellular and intravascular fluids. The maintenance of the volume of these fluids is one of the most important roles of sodium, for which the kidney regulates sodium and water excretion [7]. Sodium is also required for various physiological activities, such as nerve impulse transmission, myokinesis, absorption of nutrients in the intestine, and control of hormones. Chloride is an important anion for maintaining the cellular hydromineral balance. Several human metabolic processes, such as potassium transport, pH control, and enzyme expression, are also affected by chloride [8,9]. However, salt intake must be limited and regulated to maintain human health. In 2010, 1.65 million deaths from cardiovascular diseases were related to a sodium intake higher than the recommended value (2.0 g per day) [10]. Because excessive salt intake has negative effects on human health, the World Health Organization (WHO) recommends a 30% reduction in salt intake. Further, many campaigns have been undertaken to spread awareness about the risks of excessive salt intake [11]. Some high-income countries regulate and collaborate with the food industry to reduce sodium intake by more than 30%, resulting in a reduction in blood pressure (> 10 mmHg) and a 70% reduction in the death rate related to stroke and coronary artery disease [12]. Excessive salt intake also has significant effects on childhood obesity, and a 50% reduction in salt intake led to a reduction in the intake of sugar-sweetened soft drinks [13,14]. In addition to an increased risk of cardiovascular disorders, salt consumption has been associated with colon, gastric, rectum, pancreas, lung, testicular, bladder, and stomach cancer [15–17].

Owing to the positive effects of reducing salt intake on human health, consumer behavior is changing to favor the purchase of low-salt foods, increasing the importance of precise labeling of food packages [1]. However, reduced-salt labels can have a negative effect on consumer taste expectations, even though low-salt foods are no different from conventional foods in hedonic tests [18,19]. The willingness to pay for low-salt meat products was found to be the highest when only product-related information was provided, whereas the reserve price of low-salt meat products was the lowest among various innovative meat products (biodegradable packaging, spicy variant, and organic) only after tasting. This was because such reformulation (adding low amounts of salt) decreased the quality of these products, and consequently, decreased their hedonic scale rating [20]. Therefore, excessive information about reduced-salt products might have negative effects on the consumption of low-salt foods and the reduction of salt intake.

## **EFFORTS TO REDUCE OR REPLACE SALT**

Various governments, food industries, and health and scientific organizations have made efforts to reduce sodium intake and implement effective sodium intake strategies, such as consumer education, consumer-friendly labeling, cooperation and regulation, and food reformulation [12]. These soft regulation strategies, followed by the aforementioned organizations and companies, have been effective, and sodium intake has actually been reduced. The implementation of a color system (green, amber, and red colors corresponding to low, medium, and high salt levels, respectively) in the UK has reduced sodium intake from 3,800 mg to 3,440 mg over 4 years [21]. Furthermore, school-based education programs in China had a positive effect on sodium intake, decreasing sodium consumption by educating students and their families, and reducing the incidence rate of cardiovascular diseases, elevated blood pressure, and stroke along with their associated medical costs [22]. These strategies for the reduction of sodium consumption were associated with an increased cost-effectiveness ratio and even cost savings, which were observed not only in high-income countries, but also low-income countries, such as South Asia [23]. Such strategies, efforts, and regulations, as well as collaboration with the food industry and various organizations, would be the most efficient approach to reduce consumer sodium intake.

In line with changes in consumer behavior and government regulations, the meat processing industry has changed the formulation of their products. Without adding taste enhancers or performing other treatments, sodium chloride in meat products could be reduced by 25%, without dramatically affecting the quality characteristics of the products [24]. However, this reduction ratio does not satisfy WHO recommendations. Therefore, new strategies for salt reduction or replacement are needed, and the efforts of the food industry in this frontier would be crucial to reduce sodium intake, increase cost efficiency, and promote a healthy lifestyle. Salt-reduced meat products are accepted when their sensory evaluation and quality properties do not deteriorate. The addition of improvers, such as flavor enhancers, binders, or sodium replacers, has been practiced. More importantly, mechanical and processing technologies have been developed and are widely employed to reduce the use of salt [25].

## **EFFECT OF REDUCING SALT ON THE QUALITY OF MEAT PRODUCTS**

Salt has been used over the years to preserve products and is mainly used in processed products [26]. The most important functional properties of salt include enhancing sensory properties, imparting textural properties, and extending shelf life (Table 1). Consequently, the reduction of salt

**Table 1. Overview of the role of salt (NaCl) in meat products mentioned in the present review**

Role of salt in meat products	Reference
Increase shelf-life	
Increase microbial safety	
· Lowering the water activity ( $a_w$ ) of the product	[25,27,32]
· Exhibiting osmotic shock to the microorganism	
· Inducing electrolyte imbalance inside the microbial cell	
Increase sensory properties	
· Representing saltiness	[53,55,56]
· Suppressing bitterness and sweetness	
· Using products as flavor enhancers	
· Increasing juiciness and sensorial texture	
Increase physicochemical properties	
· Extracting myofibrillar protein (myosin, actin, etc.)	[29,46–48]
→ <i>Increasing emulsion capacity and stability</i>	
→ <i>Providing proper texture properties</i>	
· Binding Cl <sup>-</sup> to the myofibrillar protein and forming an 'Na <sup>+</sup> cloud' around the myofibrils	
→ <i>Increasing water holding capacity</i>	
→ <i>Decreasing cooking loss</i>	

in processed foods must be addressed via a technical and scientific approach, which should account for properties, such as the WHC, fat binding capacity, texture profile, sensory properties, stability, and shelf life [27]. Compared to other foods, the role and functional properties of salt are more important for meat processing.

## SAFETY PERSPECTIVE OF REDUCING SALT

Since ancient times, salt has been used to extend the shelf life of meat products. With the development of refrigeration and packaging technology, salt levels have been reduced relative to levels that were previously used; however, it still remains an essential additive in the preservation of cured meat products [28]. Salt is widely known to inhibit the growth of microorganisms, including spoilage bacteria and yeasts/molds. The antimicrobial effect of salt is mainly linked to low water activity and osmotic shock [29,30].

Water activity is defined as the ratio of the vapor pressure of a food item to that of distilled water under identical conditions. The addition of salt can reduce the vapor pressure of a food product, thereby reducing water activity [31,32]. In one study, the water activity of pure water, a 22% salt solution, and saturated salt solution were found to be lowered to 1.00, 0.86, and 0.75, respectively [33]. This water activity is related to the amount of free water needed for microbial activity; hence, low water activity can prevent microbial growth [25]. Tapia et al. [34] demonstrated that lowering water activity leads to an increase in the lag phase of microbial growth, thereby decreasing the growth rate and final population of microorganisms, as metabolic activities in cells require an aqueous environment. However, the water activity values required for microbial growth depend on the type of microorganism [35]. The minimum water activity values reported for microbial growth are listed in Table 2. Generally, most bacteria, yeast, and molds cannot grow below water activity values of 0.91, 0.88, and 0.80, respectively. The growth of *Listeria monocytogenes* or *Salmonella* spp. was inhibited in cured meat products (e.g., jerky meat) that had a water activity lower than 0.90

**Table 2. Approximate minimum water activity ( $a_w$ ) required for microbial growth**

Group of microorganisms	Specific name	Water activity ( $a_w$ )	References
Bacteria		0.90	[30]
	<i>Campylobacter jejuni</i>	0.98	[35]
	<i>Clostridium botulinum</i> , type E	0.97	[33]
	<i>Escherichia coli</i>	0.95	[35]
	<i>Salmonella</i> spp.	0.95	[35]
	<i>Clostridium botulinum</i> , types A and B	0.94	[33]
	<i>Vibrio parahaemolyticus</i>	0.94	[33]
	<i>Listeria monocytogenes</i>	0.92	[35]
Yeast		0.88	[30]
	<i>Candida utilis</i>	0.94	[33]
Molds		0.80	[30]
	<i>Aspergillus flavus</i>	0.80	[35]
Halophilic bacteria		0.75	[30]
Xerophilic molds		0.65	[30]
Osmophilic yeast		0.60	[30]

[33].

Osmotic shock can occur when the water activity of a food item (environment surrounding microorganisms) is considerably lower than that of the microorganisms [36]. Under these conditions, water is transferred from high water activity areas (lower osmotic pressure) to low water activity areas (higher osmotic pressure) through the microbial cell membrane [27]. Thus, the cytoplasmic volume of cells decreases due to osmotic shock, and is accompanied by death or serious damage [32]. According to Csonka [37], microbial cells subjected to osmotic shock had shrinkage of the cell membrane and plasmolysis. These are the main reasons why meat products with low water activity have a long shelf life [29]. Jay et al. [33] also reported that the addition of salt to food enhances osmotic stress in microbial cells and leads to cell destruction.

Other effects of salt on antimicrobial properties have also been reported in several studies. According to Petit et al. [27], because salt can cause an electrolyte imbalance within microbial cells, the microorganisms consume more energy to exclude sodium ions ( $\text{Na}^+$ ), leading to a reduction in the growth rate. In some cases, salt limits oxygen solubility and interferes with microbial cellular enzymes [38]. The direct toxicity of chloride ions ( $\text{Cl}^-$ ) on microorganisms has also been proposed; however, this hypothesis is still controversial [32].

Many studies have investigated the effects of salt on microbial growth in several meat products. Delgado-Pando et al. [39] stored ham samples containing salt levels of 2%, 1.6%, 1.0%, and 0.8%, and bacon samples containing 2.9%, 2.5%, 2%, and 1.5% at 2 °C to assess the microbial properties of the products. As a result, the number of total aerobic bacteria was found to significantly increase during storage, displaying higher microbial numbers for the products with the lowest salt level. At the end of the storage period (40 days), the number of lactic acid bacteria was significantly higher in bacon stored with 1.5% salt and ham with 0.8% and 1.2% salt compared to samples preserved with other salt concentrations. Fougy et al. [40] found that reducing salt levels (from 2.0% to 1.5%) promoted the growth of spoilage bacteria, leading to faster spoilage; however, bacterial diversity was reduced. Salt generally slows the spoilage rate by replacing natural meat flora with lactobacilli and micrococci [28]. Laranjo et al. [3] reported that in traditional Portuguese blood dry-cured sausages stored in two different salt concentrations (3% and 6%), the counts of mesophiles, staphylococci, and yeasts were significantly higher in the low-salt sample.



## PHYSICOCHEMICAL PERSPECTIVE OF REDUCED-SALT MEAT PRODUCT

The main functional role of salt in meat products is to solubilize meat myofibrillar proteins. The extraction of myofibrillar proteins improves emulsion capacity, binding capacity, texture properties, WHC, juiciness, and cooking yield [27,29].

Muscle proteins can be classified into three groups based on solubility: (i) sarcoplasmic proteins, soluble in water or low ionic strength solution; (ii) myofibrillar proteins, soluble in salt solutions with a concentration above 1%, and (iii) stromal proteins, insoluble in both water and salt solutions [41]. Among these proteins, we opted to focus on myofibrillar proteins, also called salt-soluble proteins. Myofibrillar proteins, consisting of myosin, actin, actomyosin, and other proteins, have good hydrophilicity–hydrophobicity balance and long fibrous structure; therefore, they play the most functional role in meat product processing [42]. In particular, myosin and actomyosin have high emulsifying capacity and good emulsion stability. Thus, the more the myofibrillar proteins extracted by salt, the more elastic and hard gel matrix formed in the emulsified meat products; well-emulsified meat products have a desirable texture [41,43]. Pires et al. [44] studied the microstructure of bongola sausages prepared using different salt concentrations (20%, 40%, and 60%). In their study, sausages containing higher salt content exhibited more compact and denser structures, whereas sausages with the greatest reduction in salt content had a more irregular and sponge-like appearance. This spongy structure of salt-reduced sausages was caused by low emulsion stability, making the texture of the product softer. Felisberto et al. [45] also revealed that low-salt meat emulsions have low emulsion stability, leading to a porous structure, high fluid loss, low compression strength, and low consumer acceptability.

When myofibrillar proteins are extracted with the addition of salt, they become swollen; this phenomenon is related to WHC [29]. Several studies have suggested two hypotheses to explain the effect of salt on the WHC in meat products. The first hypothesis was proposed by Hamm [46,47]. According to Hamm, as  $\text{Cl}^-$  can bind to a protein more strongly than  $\text{Na}^+$  adding salt increases the negative charge on the protein, shifting the isoelectric point to a lower pH. Thus, at a pH higher than the isoelectric point, interactions between oppositely charged groups weaken, causing swelling of the myofibrillar proteins and an increase in water binding [46,47]. Although this explanation is reasonable, it does not consider the role of sodium. Accordingly, Offer and Knight [48] suggested a second hypothesis based on the binding of  $\text{Cl}^-$  to myofibrillar proteins. The authors proposed that the  $\text{Na}^+$  form an ion “cloud” around the filaments. This “cloud” does not cause remarkable repulsion between the myofilaments, but between the molecules of myosin filaments breaking down the shafts of the filaments, thereby causing the myofibrillar lattice to loosen. These authors also proposed that the swelling induced by salt is caused by an entropic mechanism rather than an electrostatic mechanism [29]. When the NaCl concentration increases to 0.5 M without the addition of phosphates, the solubility of actin and myosin increases, and the myofibrils begin to swell [49]. Kameník et al. [26] suggested that a minimum amount of 12 g salt per 1 kg of meat is required for the effective activation of proteins.

Salt increases the WHC of meat. The isoelectric point of meat protein is around pH 5.0, and WHC is the lowest at that point. Generally, the WHC of meat proportionally increases with increasing pH, which is above the isoelectric point [49]. Here, the addition of salt to meat products could reduce the isoelectric point as increased  $\text{Na}^+$  can bind to the myofilaments and weaken the binding of  $\text{Cl}^-$ . Hamm [46] suggested that the addition of 2% salt to meat products decreases the isoelectric point from pH 5.0 to pH 4.0. For these reasons, the WHC increases when the meat pH (over the isoelectric point) is not changed; however, only the isoelectric point is reduced [49].

Restructured ham prepared with 1.2% salt showed significantly higher expressible moisture (lower WHC), cooking loss, and purge loss than ham prepared with 1.5% salt [50]. When 2.9%, 2.5%, 2%, and 1.5% of salt were added to bacon, cooking loss was 22.91%, 25.89%, 29.01%, and 38.01%, respectively [39]. Lee and Chin [51] revealed that salt reduction from 1.5% to 0.5% in ham resulted in increased cooking loss. Honikel [52] recommends at least 1.5% salt to increase the WHC of meat products.

## STRATEGIES TO IMPROVE THE SENSORY PROPERTIES OF REDUCED-SALT MEAT PRODUCT

### Perception and optimization of salt taste

Salt is related to salty taste [53]. The taste of food is detected by taste buds located in the oral mucosa of the tongue and palate. Taste buds appear as small onion-like structures and contain receptor cells that act as specific sensors for taste molecules [54]. Salt receptors are still under study; however, amiloride-sensitive epithelial sodium channels (ENaCs) have been suggested to be the most important of these receptors. When food enters the mouth and is mixed with saliva, the salt present in the food is split into  $\text{Na}^+$  and  $\text{Cl}^-$ . Later,  $\text{Na}^+$  stimulates the ENaCs, which send sensory signals to the brain, leading to the perception of salty taste [53]. To recognize saltiness, the  $\text{Na}^+$  concentration should be high enough to activate ENaCs [55].

The lowest NaCl concentration that leads to receptor activation and electrical stimulation in the brain is called the detection threshold. Sensitivity to saltiness can also be related to the recognition threshold (the lowest NaCl concentration at which the stimulus can not only be detected, but also be recognized), the differential threshold (the NaCl concentration at which an increase in the detected stimulus can be perceived), and the terminal threshold (the lowest NaCl concentration beyond which a stimulus is no longer detected) [19]. The recognition threshold for cooking salt is approximately 9 g of salt per 1,000 g of water or other solutes; however, it can vary based on gender, age, and eating habits [27]. In addition, repeated exposure to salt-reduced foods results in increased sensitivity to salty taste, which may in turn, lower the threshold for the detection of saltiness without any changes in acceptability [56].

Salt is commonly used to enhance the organoleptic characteristics of meat products [53]. The taste and flavor of meat products are determined by the amount of added salt; hence, with a considerable decrease in salt content, saltiness decreases and the taste worsens [55]. In a study on ground cooked hams, hams prepared with 1.1% salt were rated less salty than those prepared with 2.6% salt [57]. Owing to these sensorial properties, it is difficult to reduce or replace all of the commonly added salt contents. However, several studies have revealed that an appropriate extent of salt reduction does not significantly affect the taste or flavor of meat products [25]. Compared to sausages with 2.19% salt, sausages with 1.23% salt differed in their salty, sausage, smoky, and spicy flavors; however, sausages with 1.74% salt did not differ with respect to these sensory properties [58]. According to Pietrasik and Gaudette [50], traditional ham (2% salt) and salt-reduced ham (1.2% salt) showed no significant differences in their after-taste and flavor. When frankfurters prepared with 1.5% and 1.0% salt were stored for 4 weeks at 4°C, their flavor scores in a sensory test were the same regardless of salt content or storage period [59]. In addition, salt reduction in bacon (from 2.9% to 1.5%) did not affect the meaty flavor, metallic taste, or sweet aftertaste in the hedonic sensory perspectives [39]. Tunieva and Gorbunova [55] revealed that even if the salt content in meat products is reduced, the salty taste can be improved by optimizing the crystal size and shape of the salt crystals. Thus, it is possible to make salt-reduced meat products that do not differ in taste and flavor from common meat products.

In addition to the issues of taste and flavor reduction, salt reduction in meat products affects other organoleptic properties, including texture and juiciness [27]. Lee and Chin [51] demonstrated that different salt levels (1.5% and 1.0%) in restructured ham affected the texture, juiciness, and color of the product, but did not affect its flavor. Salt reduction (2.0%, 1.6%, 1.2%, and 0.8%) in ham products is correlated with a decrease in tenderness and the intensity of juiciness [39]. Reducing salt in frankfurters (from 2.1% to 1.7%) also reduces their sensory hardness and consumers' perception of taste [60]. The reduction in salt concentration decreases the texture and juiciness of meat products because salt changes the physicochemical properties of the products, such as their binding capacity, emulsion capacity, or WHC [25]. In the next section, we discuss various strategies to improve the sensory properties of reduced-salt meat products.

### Sensory evolution of reduced-salt meat products with various improvement strategies

As quality characteristics could worsen, many researchers have studied and developed strategies to improve the quality of reduced-salt meat products. When flavor is the focus, decreasing the added amount of salt might have no effect on the flavor or texture of various meat products. However, excessive amounts of regulated salt can induce unsavory meat products. Therefore, flavor enhancers or sodium chloride replacers must be added to meat products to reduce sodium chloride content (Table 3).

Fellendorf et al. [61] reported that the combination of potassium lactate and glycine could replace 60% of NaCl without having any effect on sensory items, except for saltiness. Structural transformation could be an approach to replace and reduce refined NaCl. Soda-Lo® salt microspheres are known to reduce sodium chloride by 25% of sodium. Raybaudi-Massilia et al. [62] revealed the effects of this replacement on the sensory properties of cooked ham, turkey breast, and Deli-type sausages. Each meat product had different amounts of sodium reduction (21.93%, 10%, and 30.07%). Among various salt replacers, Artisalt™ could replace commercial salt. Previously, O'Neill et al. [63] suggested that Artisalt™ displayed a higher efficiency when high pressure and organic acids (Inbac™) are employed. Other metal ions, such as potassium, magnesium, and/or calcium can be used as sodium replacers [61,64]. However, because these metal ions have negative effects on the sensory properties, flavor enhancers must be added. When Fellendorf et al. [61] mixed NaCl, KCl, CaCl<sub>2</sub>, and MgCl<sub>2</sub>, they found that the acceptability of corned beef supplemented with mixed salt was significantly lower than that of the control. Potassium lactate, phosphate potassium, and glycine were used to improve the sensory properties. Vidal et al. [64] used KCl as a replacement for NaCl. The decreased sensory properties of salted meat, such as color and overall acceptability, could be prevented by lysine and yeast extracts (Bionis YE MXE NS). In addition, Vidal et al. [64] reported that hydrocolloids could positively affect the physicochemical properties of frankfurters. Although appearance, aroma, and color properties were decreased, flavor, texture, and overall acceptability of reduced-salt frankfurters supplemented with 1% of edible seaweed (*Himantalia elongate*) were not significantly different from those of the control frankfurters [65].

Various researchers have reported the effect of salt reduction on the sensory evaluation of meat products. Fellendorf et al. [61] reported that 60% of salt could be reduced without any impact on the sensory effects, except for saltiness. For dry-cured ham, the decreased salt content was found to have a significant effect on redness, marbling, saltiness, hardness, fibrousness, and overall quality [66]. However, consumer liking of reduced-salt dry-cured ham was higher than that of the control; this is because consumers have expressed that reduced-salt dry-cured ham was healthier than the control. Laranjo et al. [67] examined the effects of salt reduction on blood dry-cured sausages. Reduced-salt sausage had lower scores for flavor, salt perception, and overall acceptability.

As salt reduction has a negative effect on various sensory items, different technologies have



**Table 3.** Improved sensory properties of the reduced-salt meat products derived using various strategies

Main strategy	Specific method <sup>1)</sup>	Meat product	Evaluated sensory items	Sodium reduction	References
<i>NaCl replacement</i>	Replaced 0.2–0.8 g/100 g with CaCl <sub>2</sub> , MgCl <sub>2</sub> , KCl, potassium lactate, potassium phosphate, and glycine (Potassium lactate and glycine with replacement of 0.4 g of NaCl/100 g of meat)	Corned beef	Hedonic test · Appearance, color, flavor, texture, acceptability · Intensity items · Saltiness <sup>2)</sup> , juiciness, toughness, corned beef flavor, cured flavor, off-flavor	40.16%	[61]
	Replaced 0%, 25%, 30%, and 50% of refined salt with Soda-Lo <sup>®</sup> (50%)	Cooked ham	Significant difference	21.93%	[62]
		Deli type sausage	Significant difference	30.07%	[62]
		Cooked turkey breast	Significant difference	10%	[62]
	Replaced 0%–100% of salt with Artisanal <sup>TM</sup> using high pressure and organic acids (Inbac <sup>TM</sup> ) (48% Artisanal <sup>TM</sup> , 580 MPa, 0.3% Inbac <sup>TM</sup> )	Frankfurters	Hedonic test · Appearance, texture, flavor, juiciness, tenderness, saltiness, off-flavor, overall acceptability	48%	[63]
	Replaced 75% of salt with KCl with lysine, taurine, arginine, sodium inosinate + sodium guanylate, Bionis YE MXE NS, Bionis SFE 201, Purac NA4 (25% NaCl + 75% KCl + 3% lysine, 50% NaCl + 50% KCl + 5% Bionis YE MXE NS)	Salted meat	Hedonic test · Color, aroma, flavor, texture, overall acceptance	17.49% and 22.23%	[64]
Replaced 50% of NaCl with 1% edible seaweed ( <i>Himantalia elongate</i> )	Frankfurters	Hedonic test · Overall acceptability, appearance <sup>2)</sup> , aroma <sup>2)</sup> , flavor, texture, color <sup>2)</sup>	35.76%	[71]	
<i>NaCl reduction</i>	Added 0.2–1.0 g/100 g (0.4 g/100 g)	Corned beef	Hedonic test · Appearance, color, flavor, texture, acceptability Intensity items · Saltiness <sup>2)</sup> , juiciness, toughness, corned beef flavor, cured flavor, off-flavor	40.16%	[61]
	Added 32 and 55 g of salt/kg of meat (32 g/kg)	Dry-cured ham	Quantitative descriptive analysis · Appearance (color homogeneity, redness <sup>2)</sup> , brightness, marbling <sup>2)</sup> ), odor (matured), flavor/taste (saltiness <sup>2)</sup> , bitterness, matured), texture (hardness <sup>2)</sup> , fibrousness <sup>2)</sup> , pastiness) Hedonic test · Overall quality <sup>2)</sup> Consumer test <sup>2)</sup>	30.36%	[65]
	Added 3% and 6% of salt	Blood dry-cured sausage	Intensity test · Color intensity, off-color, marbled, aroma intensity, off-aromas, hardness, fibrousness, succulence, flavor intensity, off-flavor <sup>2)</sup> , salt perception <sup>2)</sup> , overall acceptability <sup>2)</sup>	- <sup>3)</sup>	[66]
	Reduced 0%, 25%, and 50% of salt with ultrasound (50% with ultrasound)	Restructured cooked ham	Sensory acceptance · Color <sup>2)</sup> , taste, texture, global acceptance, purchase intention	28.22%	[67]
	Added 1.2% and 2% NaCl using pulsed electric field (1.2% with pulsed electric field)	Beef jerky	Hedonic test · Color, flavor, saltiness, tenderness <sup>2)</sup> , overall acceptability	34.29%	[68]
	Added 0.75% and 1.5% NaCl using γ-ray, X-ray, E-beam (0.75% with X-ray)	Emulsion sausage	Hedonic test · Color, flavor <sup>2)</sup> , off-flavor, tenderness, juiciness <sup>2)</sup> , saltiness <sup>2)</sup> , overall acceptability <sup>2)</sup>	-	[69]
	Added 0%, 1%, and 2% of NaCl using high pressure (1% with 200 MPa)	Chicken batter	Hedonic test · Appearance, flavor, texture, overall acceptability	-	[70]

<sup>1)</sup>The highest salt concentration that indicates the control, and the suggested condition for reducing or replacing sodium chloride are presented in parentheses according to the references.

<sup>2)</sup>The sensory item of the suggested treatment was significantly different from that of the control ( $p < 0.05$ ).

<sup>3)</sup>The sodium reduction amount was not expressed if this amount was not measured in the study.

been developed and applied. Ultrasound-treated restructured cooked ham was found to have similar sensory acceptance (taste, texture, global acceptance, and purchase intention) to control ham [68]. Further, when a nominal current of  $600 \text{ W}\cdot\text{cm}^{-2}$  was applied for 10 min, 50% of the salt was reduced. A pulsed electric field can also be applied to reduce salt. In fact, 34.29% of sodium in beef jerky could be reduced when treated with 0.52 kV/cm, 10 kV, 20 Hz, 20  $\mu\text{s}$  of pulsed electric field, with higher scores obtained for tenderness [69]. Irradiation sources have been used to improve the quality properties of reduced-salt emulsion sausages. X-rays are the most efficient sources of  $\gamma$  -rays, X-rays, and E-beams [70]. Zheng et al. [71] applied high pressure to a chicken batter and found no specific difference in the sensory properties between the reduced half salt treatment and control groups when treated at 200 MPa.

Various strategies have been developed to improve the sensory properties of meat products. In addition, quality properties or microbial safety of reduced salt meat products have been improved with various strategies hot-boning, high-pressure, radiation, ultrasound, pulsed electric fields, metallic agents, and various natural enhancement and suitable sodium reduction contents are suggested by Kim et al. [72]. In fact, the aforementioned strategies could prevent a decrease in the quality deterioration of meat products. Moreover, consumers have expressed that less saltiness is healthier.

## CONCLUSION

In this review, we examined the role of salt in the production of meat products and the latest research approaches related to salt reduction and salt replacement that are focused on sensory evaluation. We addressed the problems that may occur in low-salt meat products from various perspectives and have described methodologies to resolve these issues. The aim of refining the meat processing industry by employing alternative materials and processing technologies to reduce salt in meat products is being actively assessed. An important factor that must be considered is the use of low-salt techniques to reduce the sodium content of meat products. Because excessive salt reduction causes non-preferred meat products, various strategies have been developed. Different salt replacements, flavor enhancers, and technical processing have been found to improve the sensory properties, and thus could be employed to reduce sodium content without affecting sensory properties.

## REFERENCES

1. Bhana N, Utter J, Eyles H. Knowledge, attitudes and behaviours related to dietary salt intake in high-income countries: a systematic review. *Curr Nutr Rep.* 2018;7:183-97. <https://doi.org/10.1007/s13668-018-0239-9>
2. Raj SE, Tan LM, Md Redzuan A. Dietary salt intake: history, assessment, and benefit in hypertensive treatment. *Asian J Pharm Clin Res.* 2016;9:39-42. <https://doi.org/10.22159/ajpcr.2016.v9s2.13483>
3. Laranjo M, Gomes A, Agulheiro-Santos AC, Potes ME, Cabrita MJ, Garcia R, et al. Impact of salt reduction on biogenic amines, fatty acids, microbiota, texture and sensory profile in traditional blood dry-cured sausages. *Food Chem.* 2017;218:129-36. <https://doi.org/10.1016/j.foodchem.2016.09.056>
4. Lee CH, Chin KB. Evaluation of pork myofibrillar protein gel with pork skin gelatin on rheological properties at different salt concentrations. *Food Sci Anim Resour.* 2019;39:576-84. <https://doi.org/10.5851/kosfa.2019.e48>

5. Yim DG, Shin DJ, Jo C, Nam KC. Effect of sodium-alternative curing salts on physicochemical properties during salami manufacture. *Food Sci Anim Resour.* 2020;40:946-56. <https://doi.org/10.5851/kosfa.2020.e65>
6. Dahl LK. Possible role of salt intake in the development of essential hypertension. *Int J Epidemiol.* 2005;34:967-72. <https://doi.org/10.1093/ije/dyh317>
7. Logan AG. Dietary sodium intake and its relation to human health: a summary of the evidence. *J Am Coll Nutr.* 2006;25:165-9. <https://doi.org/10.1080/07315724.2006.10719528>
8. Brugnara C, Van Ha T, Tosteson DC. Role of chloride in potassium transport through a K-Cl cotransport system in human red blood cells. *Am J Physiol Cell Physiol.* 1989;256:C994-1003. <https://doi.org/10.1152/ajpcell.1989.256.5.C994>
9. Numao S, Maurus R, Sidhu G, Wang Y, Overall CM, Brayer GD, et al. Probing the role of the chloride ion in the mechanism of human pancreatic  $\alpha$ -amylase. *Biochemistry.* 2002;41:215-25. <https://doi.org/10.1021/bi0115636>
10. Mozaffarian D, Fahimi S, Singh GM, Micha R, Khatibzadeh S, Engell RE, et al. Global sodium consumption and death from cardiovascular causes. *N Engl J Med.* 2014;371:624-34. <https://doi.org/10.1056/NEJMoa1304127>
11. Kim TK, Kim YB, Jeon KH, Jang HW, Lee HS, Choi YS. Quality characteristics of Samgyetang according to the sodium chloride level and with/without phosphate in broth. *Food Sci Anim Resour.* 2019;39:102-13. <https://doi.org/10.5851/kosfa.2019.e8>
12. Mohan S, Campbell NRC, Willis K. Effective population-wide public health interventions to promote sodium reduction. *Can Med Assoc J.* 2009;181:605-9. <https://doi.org/10.1503/cmaj.090361>
13. He FJ, Marrero NM, MacGregor GA. Salt intake is related to soft drink consumption in children and adolescents: a link to obesity? *Hypertension.* 2008;51:629-34. <https://doi.org/10.1161/HYPERTENSIONAHA.107.100990>
14. Lava SAG, Bianchetti MG, Simonetti GD. Salt intake in children and its consequences on blood pressure. *Pediatr Nephrol.* 2015;30:1389-96. <https://doi.org/10.1007/s00467-014-2931-3>
15. D'Elia L, Galletti F, Strazzullo P. Dietary salt intake and risk of gastric cancer. In: Zappia V, Panico S, Russo G, Budillon A, Della Ragione F, editors. *Advances in nutrition and cancer.* Berlin: Springer; 2014. p. 83-95.
16. Hu J, La Vecchia C, Morrison H, Negri E, Mery L. Salt, processed meat and the risk of cancer. *Eur J Cancer Prev.* 2011;20:132-9. <https://doi.org/10.1097/CEJ.0b013e3283429e32>
17. Wang XQ, Terry PD, Yan H. Review of salt consumption and stomach cancer risk: epidemiological and biological evidence. *World J Gastroenterol.* 2009;15:2204-13. <https://doi.org/10.3748/wjg.15.2204>
18. Antúnez L, Giménez A, Alcaire F, Vidal L, Ares G. Consumer perception of salt-reduced breads: comparison of single and two-bites evaluation. *Food Res Int.* 2017;100:254-9. <https://doi.org/10.1016/j.foodres.2017.07.014>
19. Liem DG. Infants' and children's salt taste perception and liking: a review. *Nutrients.* 2017;9:1011. <https://doi.org/10.3390/nu9091011>
20. Żakowska-Biemans S, Sajdakowska M, Issanchou S. Impact of innovation on consumers liking and willingness to pay for traditional sausages. *Pol J Food Nutr Sci.* 2016;66:119-27. <https://doi.org/10.1515/pjfn-2016-0004>
21. He FJ, MacGregor GA. A comprehensive review on salt and health and current experience of worldwide salt reduction programmes. *J Hum Hypertens.* 2009;23:363-84. <https://doi.org/10.1038/jhh.2008.144>

22. Li X, Jan S, Yan LL, Hayes A, Chu Y, Wang H, et al. Cost and cost-effectiveness of a school-based education program to reduce salt intake in children and their families in China. *PLOS ONE*. 2017;12:e0183033. <https://doi.org/10.1371/journal.pone.0183033>
23. Nghiem N, Blakely T, Cobiac LJ, Cleghorn CL, Wilson N. The health gains and cost savings of dietary salt reduction interventions, with equity and age distributional aspects. *BMC Public Health*. 2016;16:423. <https://doi.org/10.1186/s12889-016-3102-1>
24. Olson DG. Salt for processing probably can be cut by only one quarter. *Natl Provisioner*. 1982;17:7-10.
25. Inguglia ES, Zhang Z, Tiwari BK, Kerry JP, Burgess CM. Salt reduction strategies in processed meat products: a review. *Trends Food Sci Technol*. 2017;59:70-8. <https://doi.org/10.1016/j.tifs.2016.10.016>
26. Kameník J, Saláková A, Vyskočilová V, Pechová A, Haruštiaková D. Salt, sodium chloride or sodium? Content and relationship with chemical, instrumental and sensory attributes in cooked meat products. *Meat Sci*. 2017;131:196-202. <https://doi.org/10.1016/j.meatsci.2017.05.010>
27. Petit G, Jury V, de Lamballerie M, Duranton F, Pottier L, Martin JL. Salt intake from processed meat products: benefits, risks and evolving practices. *Compr Rev Food Sci Food Saf*. 2019;18:1453-73. <https://doi.org/10.1111/1541-4337.12478>
28. Matthews K, Strong M. Salt – its role in meat products and the industry’s action plan to reduce it. *Nutr Bull*. 2005;30:55-61. <https://doi.org/10.1111/j.1467-3010.2005.00469.x>
29. Desmond E. Reducing salt: a challenge for the meat industry. *Meat Sci*. 2006;74:188-96. <https://doi.org/10.1016/j.meatsci.2006.04.014>
30. Dilbaghi N, Sharma S. Food spoilage, food infections and intoxications caused by microorganisms and methods for their detection. In: Prajapati JB, Sannabhadti SS, Gunasekaran P, Chand S, editors. *Food and industrial microbiology*. Haryana, India: Guru Jambheshwar University of Science and Technology; 2007.
31. Halling PJ. Salt hydrates for water activity control with biocatalysts in organic media. *Biotechnol Tech*. 1992;6:271-6. <https://doi.org/10.1007/BF02439357>
32. Taormina PJ. Implications of salt and sodium reduction on microbial food safety. *Crit Rev Food Sci Nutr*. 2010;50:209-27. <https://doi.org/10.1080/10408391003626207>
33. Jay JM, Loessner MJ, Golden DA. Intrinsic and extrinsic parameters of foods that affect microbial growth. In: Jay JM, editor. *Modern food microbiology*. New York, NY: Springer; 2005. p. 39-59.
34. Tapia MS, Alzamora SM, Chirife J. Effects of water activity (aw) on microbial stability as a hurdle in food preservation. In: Barbosa-Cánovas GV, Fontana AJ Jr, Schmidt SJ, Labuza TP, editors. *Water activity in foods: fundamentals and applications*. Hoboken, NJ: John Wiley & Sons; 2020. p. 323-55.
35. Doyle ME, Glass KA. Sodium reduction and its effect on food safety, food quality, and human health. *Compr Rev Food Sci Food Saf*. 2010;9:44-56. <https://doi.org/10.1111/j.1541-4337.2009.00096.x>
36. Finan JD, Guilak F. The effects of osmotic stress on the structure and function of the cell nucleus. *J Cell Biochem*. 2010;109:460-7. <https://doi.org/10.1002/jcb.22437>
37. Csonka LN. Physiological and genetic responses of bacteria to osmotic stress. *Microbiol Mol Biol Rev*. 1989;53:121-47. <https://doi.org/10.1128/MMBR.53.1.121-147.1989>
38. Shelef LA, Seiter J. Indirect and miscellaneous antimicrobials. In: Davidson PM, Sofos JN, Branen AL, editors. *Antimicrobials in food*. 3rd ed. New York, NY: CRC Press; 2005. p. 573-98.
39. Delgado-Pando G, Fischer E, Allen P, Kerry JP, O’Sullivan MG, Hamill RM. Salt content and

- minimum acceptable levels in whole-muscle cured meat products. *Meat Sci.* 2018;139:179-86. <https://doi.org/10.1016/j.meatsci.2018.01.025>
40. Fougy L, Desmots MH, Coeuret G, Fassel C, Hamon E, Hézard B, et al. Reducing salt in raw pork sausages increases spoilage and correlates with reduced bacterial diversity. *Appl Environ Microbiol.* 2016;82:3928-39. <https://doi.org/10.1128/AEM.00323-16>
  41. Santhi D, Kalaikannan A, Sureshkumar S. Factors influencing meat emulsion properties and product texture: a review. *Crit Rev Food Sci Nutr.* 2017;57:2021-7. <https://doi.org/10.1080/10408398.2013.858027>
  42. Smith DM. Functional properties of muscle proteins in processed poultry products. In: Owens CM, Alvarado C, Sams AR, editors. *Poultry meat processing*. Boca Raton, FL: CRC Press; 2001. p. 181-94.
  43. Xiong YL. Muscle proteins. In: Yada RY, editor. *Proteins in food processing*. 2nd ed. Cambridge, UK: Woodhead; 2018. p. 127-48.
  44. Pires MA, Munekata PES, Baldin JC, Rocha YJP, Carvalho LT, dos Santos IR, et al. The effect of sodium reduction on the microstructure, texture and sensory acceptance of bologna sausage. *Food Struct.* 2017;14:1-7. <https://doi.org/10.1016/j.foostr.2017.05.002>
  45. Felisberto MHF, Galvão MTEL, Picone CSF, Cunha RL, Pollonio MAR. Effect of prebiotic ingredients on the rheological properties and microstructure of reduced-sodium and low-fat meat emulsions. *LWT-Food Sci Technol.* 2015;60:148-55. <https://doi.org/10.1016/j.lwt.2014.08.004>
  46. Hamm R. Importance of meat water binding capacity for specific meat products. In: *Kolloid-chemie des fleisches*. Berlin, Germany: Paul Parey; 1972. p. 215-22.
  47. Hamm R. Functional properties of the myofibrillar system and their measurements. In: Bechtel PJ, editor. *Muscle as food*. Orlando, FL: Academic Press; 1986. p. 135-99.
  48. Offer G, Knight P. The structural basis of water-holding in meat. In: Lawrie RA, editor. *Development in meat science-4*. London, UK: Elsevier Applied Science; 1988. p. 63.
  49. Ruusunen M, Puolanne E. Reducing sodium intake from meat products. *Meat Sci.* 2005;70:531-41. <https://doi.org/10.1016/j.meatsci.2004.07.016>
  50. Pietrasik Z, Gaudette NJ. The impact of salt replacers and flavor enhancer on the processing characteristics and consumer acceptance of restructured cooked hams. *Meat Sci.* 2014;96:1165-70. <https://doi.org/10.1016/j.meatsci.2013.11.005>
  51. Lee HC, Chin KB. Evaluation of various salt levels and different dairy proteins in combination with microbial transglutaminase on the quality characteristics of restructured pork ham. *Int J Food Sci Technol.* 2011;46:1522-8. <https://doi.org/10.1111/j.1365-2621.2011.02654.x>
  52. Honikel KO. The use and control of nitrate and nitrite for the processing of meat products. *Meat Sci.* 2008;78:68-76. <https://doi.org/10.1016/j.meatsci.2007.05.030>
  53. Roper SD. The taste of table salt. *Pflügers Arch.* 2015;467:457-63. <https://doi.org/10.1007/s00424-014-1683-z>
  54. Dötsch M, Busch J, Batenburg M, Liem G, Tareilus E, Mueller R, et al. Strategies to reduce sodium consumption: a food industry perspective. *Crit Rev Food Sci Nutr.* 2009;49:841-51. <https://doi.org/10.1080/10408390903044297>
  55. Tunieva EK, Gorbunova NA. Alternative methods of technological processing to reduce salt in meat products. *Theory Pract Meat Process.* 2017;2:47-56. <https://doi.org/10.21323/2414-438X-2017-2-1-47-56>
  56. Hoppu U, Hopia A, Pohjanheimo T, Rotola-Pukkila M, Mäkinen S, Pihlanto A, et al. Effect of salt reduction on consumer acceptance and sensory quality of food. *Foods.* 2017;6:103. <https://doi.org/10.3390/foods6120103>



57. Ruusunen M, Särkkä-Tirkkonen M, Puolanne E. Saltiness of coarsely ground cooked ham with reduced salt content. *Agric Food Sci.* 2001;10:27-32. <https://doi.org/10.23986/afsci.5676>
58. Aaslyng MD, Vestergaard C, Koch AG. The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Sci.* 2014;96:47-55. <https://doi.org/10.1016/j.meatsci.2013.06.004>
59. Hwang KE, Kim TK, Kim HW, Oh NS, Kim YB, Jeon KH, et al. Effect of fermented red beet extracts on the shelf stability of low-salt frankfurters. *Food Sci Biotechnol.* 2017;26:929-36. <https://doi.org/10.1007/s10068-017-0113-3>
60. McGough MM, Sato T, Rankin SA, Sindelar JJ. Reducing sodium levels in frankfurters using naturally brewed soy sauce. *Meat Sci.* 2012;91:69-78. <https://doi.org/10.1016/j.meatsci.2011.12.008>
61. Fellendorf S, Kerry JP, Hamill RM, O'Sullivan MG. Impact on the physicochemical and sensory properties of salt reduced corned beef formulated with and without the use of salt replacers. *LWT-Food Sci Technol.* 2018;92:584-92. <https://doi.org/10.1016/j.lwt.2018.03.001>
62. Raybaudi-Massilia R, Mosqueda-Melgar J, Rosales-Oballos Y, Citti de Petricone R, Frágenas NN, Zambrano-Durán A, et al. New alternative to reduce sodium chloride in meat products: sensory and microbiological evaluation. *LWT-Food Sci Technol.* 2019;108:253-60. <https://doi.org/10.1016/j.lwt.2019.03.057>
63. O'Neill CM, Cruz-Romero MC, Duffy G, Kerry JP. The application of response surface methodology for development of sensory acceptable, low-salt, shelf-stable frankfurters using high-pressure processing and a mix of organic acids. *Eur Food Res Technol.* 2019;245:1277-91. <https://doi.org/10.1007/s00217-019-03243-x>
64. Vidal VAS, Santana JB, Paglarini CS, da Silva MAAP, Freitas MQ, Esmerino EA, et al. Adding lysine and yeast extract improves sensory properties of low sodium salted meat. *Meat Sci.* 2020;159:107911. <https://doi.org/10.1016/j.meatsci.2019.107911>
65. Vilar EG, Ouyang H, O'Sullivan MG, Kerry JP, Hamill RM, O'Grady MN, et al. Effect of salt reduction and inclusion of 1% edible seaweeds on the chemical, sensory and volatile component profile of reformulated frankfurters. *Meat Sci.* 2020;161:108001. <https://doi.org/10.1016/j.meatsci.2019.108001>
66. Schivazappa C, Virgili R. Impact of salt levels on the sensory profile and consumer acceptance of Italian dry-cured ham. *J Sci Food Agric.* 2020;100:3370-7. <https://doi.org/10.1002/jsfa.10370>
67. Laranjo M, Gomes A, Agulheiro-Santos AC, Potes ME, Cabrita MJ, Garcia R, et al. Impact of salt reduction on biogenic amines, fatty acids, microbiota, texture and sensory profile in traditional blood dry-cured sausages. *Food Chem.* 2017;218:129-36. <https://doi.org/10.1016/j.foodchem.2016.09.056>
68. Barretto TL, Pollonio MAR, Telis-Romero J, da Silva Barretto AC. Improving sensory acceptance and physicochemical properties by ultrasound application to restructured cooked ham with salt (NaCl) reduction. *Meat Sci.* 2018;145:55-62. <https://doi.org/10.1016/j.meatsci.2018.05.023>
69. Bhat ZF, Morton JD, Mason SL, Bekhit AEDA. The application of pulsed electric field as a sodium reducing strategy for meat products. *Food Chem.* 2020;306:125622. <https://doi.org/10.1016/j.foodchem.2019.125622>
70. Song DH, Kim HW, Hwang KE, Kim YJ, Ham YK, Choi YS, et al. Impacts of irradiation sources on quality attributes of low-salt sausage during refrigerated storage. *Korean J Food Sci Anim Resour.* 2017;37:698-707. <https://doi.org/10.5851/kosfa.2017.37.5.698>
71. Zheng H, Han M, Yang H, Tang C, Xu X, Zhou G. Application of high pressure to chicken

meat batters during heating modifies physicochemical properties, enabling salt reduction for high-quality products. *LWT-Food Sci Technol.* 2017;84:693-700. <https://doi.org/10.1016/j.lwt.2017.06.006>

72. Kim TK, Yong HI, Jung S, Kim HW, Choi YS. Technologies for the production of meat products with a low sodium chloride content and improved quality characteristics: a review. *Foods.* 2021;10:957. <https://doi.org/10.3390/foods10050957>