Chapter

The Role of Salt on Food and Human Health

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Abstract

Throughout time, salt (sodium chloride) played an important role in human societies. In ancient times, salt was used as a form of currency and to preserve foods, such as meat and fish. Besides, salt also assumed a major importance as food flavour enhancer. However, excessive salt consumption could result in serious health problems, related with hypertension and cardiovascular diseases, although this might be a controversial topic in the near future. The World Health Organization has made several policy recommendations to reduce salt intake and even implemented some policy approaches in several countries worldwide. Nevertheless, according to the European Food Safety Authority, approximately 75% of the salt we eat is already in the foods we buy. Thus, the best way to assure an effective reduction in salt consumption is to train our taste to the flavour of low-salt foods, although there is still a long way to go from awareness to action. The main goal of this chapter is to review the social and economic importance of salt throughout human history; its role in food preservation, food safety and food sensory evaluation; the impact of salt intake on human health; and the attempts to reduce or replace salt in food.

Keywords: sodium chloride, food safety, flavour, cardiovascular diseases, salt reduction, salt substitutes, history of salt

1. Introduction

Salt, also known as table salt or sodium chloride, is an ionic compound with the chemical formula NaCl, representing a 1:1 ratio of sodium and chloride ions.

The meekest of seasonings, table salt is commonly used as a condiment and food preservative. However, it was a precious commodity that played an important part in the development of the ancient world. For most of human history, salt was considered an extremely valuable commodity, as valuable as gold among ancient civilisations.

Therefore, salt was known as the "white gold", although several other commodities, such as sugar, cotton, marbles, ivory and water, also received that designation [1–9].

Salt was such an important commodity throughout world history that the word *salary* is linked to how wages were once paid in salt. Furthermore, the origins of the word *soldier* are also related to someone who was paid in salt [1].

In the centuries prior to the invention of electricity and refrigeration, salt was primarily used to preserve food. It was also a key ingredient in the curing of leather [1].

Salt has had the same economic importance as oil throughout most of human history. Therefore, in ancient times countries built their salt reserves before they went to war, so that enough food could be preserved for the forces being sent into battle [1].

Besides, salt was often taxed by nations and empires in the course of history. During the French Revolution, in regions where salt was scarce, it was worth up to 20 times more than in salt-producing regions. The death penalty was applied for smuggling salt! In India in 1930, the "salt tax" essentially made it illegal to sell or produce salt in competition with the established British monopoly on salt production. The quest for salt also played a crucial role in several battles in the American Civil War. For example, salt workers were exempt from being drafted into the army [1].

Currently, table salt, namely, sodium chloride (NaCl), is important in foods mainly due to its role on sensory appreciation, processing technology and preservation.

According to the European Food Safety Authority (EFSA), approximately 75% of the salt we eat is already in the foods we buy [10].

Nowadays, there is a growing concern with making foods nutritionally more balanced. Therefore, with the purpose of developing healthier foods, food reformulation is underway and comprises the modification of food composition by reducing or replacing ingredients, such as salt, fat and sugar [11]. In fact, recent studies have suggested that the biggest reductions in salt consumption were achieved by comprehensive strategies, such as food reformulation and media campaigns, associated to food policies, namely, regulations, taxation, mandatory reformulations and food labelling, while individual interventions on consumer education and dietary counselling have almost no effect [12, 13].

Despite the clear implications of excessive salt consumption for public health, moving from consumer awareness to action still seems to be a huge step to take [14]. Nevertheless, the adaptation to a less salty taste by consumers can be an important way to reduce salt content in food products [15–18]. Therefore, distinct strategies to implement salt reduction initiatives in different countries and among different target populations are needed [13].

2. The role of salt in food preservation

Salt is well-known for its role as flavouring agent and as food preservative both in industrial food processing and home cooking. Nevertheless, salt shows different technological properties in food production.

Dehydration was the earliest curing process, and, in order to preserve foods during dehydration, early civilizations salted foods to help desiccate them. Nowadays, this practice is still used.

Salt acts as a preservative by reducing the availability of water in foods, thereby depriving microorganisms from using available water as a nutrient [19, 20] and decreasing enzymatic activity [20]. The growth of pathogens and spoilage microorganisms is avoided or delayed in the presence of salt [20]. *Clostridium perfringens* and *Clostridium botulinum* are severely inhibited by salt, but *Staphylococcus aureus* and *Listeria monocytogenes* are relatively halotolerant [21].

Salt can be added to food products to assist in reducing and preventing microbial growth [22, 23]. This may be achieved either due to the bacteriostatic role of salt [24] or because of its ability to regulate enzyme activity [24], for example, through its influence on the growth of fermenting bacteria [20]. The main mechanisms responsible for the inhibition of microorganisms by salt include cellular plasmolysis, inhibited respiration, o-nitrophenyl-β-galactoside hydrolysis, glucose utilisation, prevention of substrate transport into the cells across cell membranes, limiting oxygen solubility and interference with enzymes [21]. Furthermore, sodium chloride may decrease enzymatic activity by denaturing enzymes, by reducing their catalytic activities and by altering their cofactors [25].

Salt can help to extend the shelf life of cured meat products, such as dry-cured ham, bacon and ham [26] or canned fish, namely, sardines, tuna, mackerel or anchovies, among others [27].

3. The technological role of salt in food production

Nowadays, the functional properties of salt in food processing and food production go well beyond taste. In fact, salt plays different technological roles in food production. Besides flavour, it has an important role also in safety and on textural properties. It also influences the growth of bacteria involved in fermentation processes [20].

Salt plays several main roles in the processing of different foods [23]:

Meat and meat products—It increases the water-holding capacity, tenderises raw meat and improves the binding of batters in processed meats.

Bread—It makes gluten more stable and less extensible and sticky, and it influences the fermentation rate.

Cheese—It modulates the microbiota, regulating the activity of starters and modifying enzyme activities, and it affects the cheese's body/texture by altering protein structure.

Canned foods—It can be used for cleaning fish, before canning.

Salt not only gives foods a "salty" flavour, but it can also enhance other flavours, such as aromatic notes. It balances sweetness and helps suppress flavours, such as bitterness.

Salt or better sodium chloride can also be a nutrient source for sodium, an essential nutrient needed by the body in small amounts.

Salt also plays a role as texture enhancer. It modifies the structure of proteins and modifies the interaction of proteins with other components, such as water and fat, which impacts the texture of foods. For example, if the proper amount of salt is added, cheese can have more body, meat can be juicier, and fish and breads can be firmer.

According to Akkerman et al. [28], low-salt cheeses were found to be less firm and more compressible. Moreover, Jian-Qiang et al. [29] studied mozzarella cheese and reported that salt content had influence on the meltability of no-salted immature cheeses.

Salt is also important as a binding and emulsifying agent. The new protein structure helps to hold the product together and helps to prevent moisture and fat loss. This is very important, for example, in processed meats.

NaCl has a main role in cheese manufacturing, namely, regulating the coagulant, the milk proteinase and microbial enzymes [30].

The gelling ability of food proteins is an important functional attribute for food manufacturing. The food industry uses different proteins to produce gels or gel-containing products which exhibit various rheological properties, appearance and gel point. Gelation is a basic process in the processing of various foods, namely, meat and other meat products, bread and bakery doughs, dairy products and fish products, among others. Salt, sugar and fat, included in the formulations of most food products, modify the properties gels, affecting the rheological and textural characteristics of foods [31].

3.1 Meat and meat products

Salt is undoubtedly the most ancient known ingredient, performing numerous functions in meat. Its addition to sausages' meat batters is mainly due to its activity in reducing water activity (a_W), functioning as bacteriostatic, controlling the growth of pathogenic microorganisms [32]. However, salt has many other effects of unquestionable interest. Salt promotes flavour and diminishes pH, which, due to the Donnan effect [33, 34], causes a decrease in the isoelectric point of proteins and consequently a higher water-holding ability.

Goutefongea [34] mentions that for salt concentrations of 10%, most salt-sensitive bacterial forms are inhibited, while salt concentrations of 5% only inhibit anaerobic forms. More recently, due to demands related to consumer preferences, the salt concentrations used in meat products in the countries that are more aware of consumers' health does not exceed 3% [35]. However, in many other countries, such as Portugal, salt contents close to 6% are still found in traditional sausages, although there is a growing concern to reduce salt.

Salt is also added to some meat and meat products to influence water-holding capacity and give the products a moister texture [36]. Ionic strength, which is influenced by salt content, has a strong influence in gel formation. The use of approximately 2–3% sodium chloride in meat products is necessary to solubilise myofibrillar proteins [32, 36]. Therefore, salt improves texture.

Salt can also help to enhance flavour and colour [37, 38]. It can affect the final flavour through the control of the biochemical and enzymatic reactions throughout ripening [39].

3.2 Bread and bakery products

Salt is very important for the bakery industry because it can make dough texture a little stronger and tighter. Furthermore, it has an impact in the shelf life of baked goods, because it reduces water activity.

The main function of salt in bread is to bring out the good flavours and mask the off-flavours. Usage levels are usually around 2%. Legislation may vary from country to country because the intake of too much salt is considered as a health risk.

Salt helps slow down chemical reactions, including controlling the fermentation rate of yeast and dough development. Salt helps control yeast activity and strengthens the protein matrix that forms the crumb structure of the bread. It is, therefore, of utmost importance that the salt is completely dissolved in doughs. In addition to impacting flavour, salt also inhibits fermentation due to the osmotic pressure effect. Yeast cells will partially dehydrate due to the osmotic pressure. The effect of salt on fermentation can be used to control the fermentation process: salt can be added, for instance, to sponges to slow down the fermentation rate. Slowing down fermentation rate means that less sugars are metabolised into acids. The result is that the pH of the dough will be higher, and the crust colour will be darker. Salt also influences enzyme activity. Additionally, salt toughens the gluten; it has a conditioning effect on the dough. Weaker flours could be strengthened by adding salt. It can be used to improve the handling properties of the dough by reducing the stickiness. Even though it strengthens the gluten, it delays its formation during mixing. Salt lengthens the mixing time, so it is common to delay the addition of the salt to the mixer. Faster flour hydration is also seen with delayed salt. The reason why salt toughens the gluten must be sought in the fact that gluten is made of negatively charged proteins. Negatively charged molecules will repel and not attract each other. It is believed that the positive sodium ions (Na^+) of salt play a role in bringing the protein molecules closer to each other. Finally, bread with no salt will also has a crust which is lighter in colour (given the same baking time and oven temperature). This can be explained as follows. Salt will slow down fermentation, so when there is no salt, the yeast activity will increase, i.e. the yeast will metabolise more sugar in the same amount of time. As a result, there will be less sugars left in the dough, and the pH of the dough will be lower (more acids will be formed). Sugars play (together with proteins, moisture and heat) an important role in the Maillard reaction [40]. This reaction is a chemical and nonenzymatic browning reaction between an amino acid or a protein with a free amino group and a reducing sugar during the thermal processing and storage of foods [41]. In this reaction melanoidins are intermediate compounds, which are responsible for the resulting brown colour [40, 41]. However, the Maillard reaction is also influenced by pH: a higher pH will speed up the Maillard reaction. Therefore, in the case where the pH is lower and where there are less sugars left, the colour of the crust is lighter [42].

3.3 Other food products

Salt and milk proteins interact to provide an essential water-binding function. Furthermore, salt acts as a flavour enhancer and preservative in cheeses. In fact, salt has three major functions in cheese: it acts as a preservative, contributes directly to flavour and is a source of dietary sodium. Together with the desired pH, water activity and redox potential, salt assists in cheese preservation by minimising spoilage and preventing the growth of pathogens [43].

Seafood products or fishery and shellfish products include all wild or farmed seawater or freshwater fish, crustaceans, molluscs and surimi, whether fresh, frozen, cooked, salted, dried, smoked, fermented and marinated, as well as sushi [44, 45].

Fish and shellfish have been acknowledged for being high-protein, low-calorie foods rich in essential polyunsaturated fatty acids. They are also considered a valuable source of minerals and vitamins. However, they are quite perishable, mainly due to their intrinsic composition and habitat. This fact has contributed to the development and improvement of seafood preserving methods since ancient times [46].

Nowadays, salt is still used for seafood preservation, mainly in developing countries, although most salted fish and shellfish products are lightly salted, and for preservation other hurdles are used as well [46].

Salt favours lipid oxidation, accelerating rancidity and consequently affecting colour and flavour [47].

Salting is a process used in the preservation of several fish products, such as salted cod, sea bream, chub mackerel and smoked salmon, among others [48].

Cod (*Gadus morhua* L.) is a white fish traditionally commercialised as salted cod in Mediterranean countries. Different salting methods may be used for cod salting, giving the final product distinct characteristics [49].

Traditionally ripened herring is a protected product in Denmark. Beheaded herrings are put in plastic barrels with salt, sugar and some spices and kept for 36 months under refrigeration. This salting/ripening process is important mainly to produce a well-ripened product with a tender consistency and a pleasant taste and odour [50].

In the preparation of smoked fish products, such as smoked salmon, salt also plays an important role, since it decreases a_W [51].

The major five dietary sources of sodium in the USA are ready-to-eat (RTE) foods, namely, bread and rolls, meat products, pizza, poultry and soups [52].

Flavour enhancement is one of the primary functions of salt in processed and ready-to-eat foods. Moreover, salt is one of the tools used for preservation to control microbial growth.

In the processing of vegetable products, salt can be used as a preservative and/or softening agent but also in the fermentation process [48].

Salt plays a role in the flavour of cereals and other snack foods [53] and provides a texture and flavour enhancing function in crackers.

In sauces, such as mayonnaise, and dressings, salt is used for preservation purposes but also as a texturing and emulsifying agent [54].

Ready-to-eat shrimp, due to its processing, cooking in salted water, is also an RTE food with a high-salt, high-sodium content.

In canned foods, salt is added mainly to preserve the product.

4. Salt consumption and human health

Despite all the health problems associated to salt consumption, its excessive use is constantly growing. Ninety-five percent of the world's population in 2013 presented a mean salt intake between 6 and 12 g/day [55], and even nowadays the average of 9–12 g per day is pointed out by the World Health Organization (WHO). Many changes are necessary to reduce salt intake and achieve the necessary reduction in high blood pressure. All the WHO member states assumed the compromise of reducing by 30% the salt intake in their populations until 2025, estimating that 2.5 million deaths can be prevented with the adequate salt consumption [56].

In fact, hypertension, which constitutes one of the risk factors for cardiovascular disease, particularly coronary heart disease and stroke, is highly correlated with the excessive consumption of salt in the human diet [57]. On the other hand, hypertension has been associated with high intakes of sodium through the sodium chloride (NaCl) used in food. Still, sodium is important for distinct physiological functions and is essential for cellular homeostasis [58].

The WHO recommends that adults consume less than 5 g (just under a teaspoon) of salt per day [56].

This mineral is essential for human health to maintain plasma volume, regulating body water content and electrolyte balance, transmission of nerve impulses and normal cell function; however, its excess in human diet leads to high blood pressure. This problem is often correlated with high consumption of sugar and fat, besides salt.

However, a decrease in potassium intake and an unhealthy lifestyle are responsible for the increased numbers of noncommunicable diseases (NCDs). NCDs, also known as chronic diseases, result from a combination of genetic, physiological, environmental and behavioural factors and are generally prolonged in duration [12, 59]. The main types of NCDs are cardiovascular diseases (like heart attacks and strokes), cancers, chronic respiratory diseases (such as chronic obstructive pulmonary disease and asthma) and type 2 diabetes [59]. The "Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013–2020" include a 30% relative reduction in the intake of salt by 2025.

According to the WHO (2018), NCDs are the cause of 41 million deaths of people each year, being cardiovascular diseases the first cause of death. Cardiovascular disease is the leading cause of death in the USA [60].

The trials that studied the role of salt in the blood pressure begun with the studies in rats of Goldblatt [61]. Some years later, Kempner [62] stated for the first time that high salt could induce hypertension and low salt could lower blood pressure. This was followed by a huge number of clinical studies about sodium restriction to control blood pressure. The result of numerous trials along the years pointed out the importance of a diet with low income of salt to decrease blood pressure. Sacks et al. [63], in a meta-analysis of 31 trials, obtained a decrease of 5.0 mmHg of systolic and 2.7 mmHg diastolic blood pressure because of a decrease of 4 g of salt per day (which corresponds to sodium 75 mmol/day) in hypertensive patients.

However, nowadays, some researchers criticise these evidences referring that most trials evaluated high blood pressure, malnourished and mainly aged patients [64]. So, according to McCarron et al. [65] and Graudal and Jürgens [66], the proposed salt daily intake for healthy people (normal blood pressure), and even the evidence of its negative role on blood pressure, should be reconsidered by health institutions and their policies.

Another aspect to be considered in human health is the necessity to evaluate jointly low sodium and high potassium intake, because high potassium consumption has a beneficial effect in preventing hypertension [67]. Potassium is present mainly in fruits, vegetables and unrefined foods and is essential for regulating fluid balance and controlling the electrical activity of the heart and other muscles and maintains normal cell function. Increased potassium intake reduced blood pressure, and it can mitigate the negative effects of elevated sodium consumption on blood pressure [68]. The WHO suggests a potassium intake of at least 3510 mg/day for adults.

The food reformulation, concerning modification in food composition with the development of healthier products, and at the same time consumer acceptance, is one strategy to achieve sodium reduction and a better intake of potassium in the human diet. Some countries, in Europe, published legislation for food reformulation by setting maximum levels for certain food components or by defining health targets. The National Salt Reduction Initiatives, developed in 2009, has the goal of reaching the maximum recommended intake of 5 g salt all over Europe.

Some recent findings indicate that human sodium intake is controlled by physiology and cannot be modified by public health policies [65].

Nevertheless, the reduction of the dietary salt intake remains a global public health priority [14].

5. Salt reduction and replacement studies

If the consumption of high levels of sodium (table salt contains 38.1% sodium) has been associated with hypertension, much effort has been spent on the complete or partial replacement of table salt (sodium chloride). It is not the salt as such, which is the culprit, but the sodium in the salt. Therefore, when discussing salt reduction, one must consider all sources of sodium.

Strategies on how to reduce salt content in food products without depreciating their quality have been proposed by several institutional and health-related organisations that recommend cooking with little or no added salt, valorising the natural taste of foods. The strategies may include, among others, seasoning with aromatic herbs, spices, lemon juice, wine and vinegar; use of marinades and garlic vines to season foods the day before; combining tasteless foods with foods of more intense flavour, such as onion, garlic, pepper and tomato; cooking with low amounts of water, to concentrate aroma and flavours; no addition of salt if the meal contains preprepared sauces, sausages or canned food; avoiding adding more salt while cooking; and not putting the salt shaker on the table.

Plain salt reduction studies are shown in **Table 1**.

Salt reduction can further be achieved in three main ways: replacement of sodium chloride by potassium chloride, addition of a flavour enhancer that enhances the salty taste even with lower salt contents and changing the physical structure of sodium chloride so that its crystals dissolve faster in the mouth, tasting saltier [47].

The most popular approach in reducing sodium chloride (NaCl) in the formulation of food products is to replace it with other chloride salts such as KCl, LiCl, $CaCl_2$ or $MgCl_2$ [36].

Potassium chloride (KCl) has been used as the main alternative to NaCl in salt replacement experiments, mostly because its antimicrobial effectiveness has been reported to be similar to that of NaCl [80].

Food product	Salt content		Reference
	Control (%)	Low salt (%)	
Traditional blood dry-cured sausages	6.0	3.0	[69]
"*Catalão*" and "*Salsichão*"	6.0	3.0	[70]
Hotdog sausages	3.6	2.8/2.0	[71]
Bacon	4.3	3.4/2.3	[71]
Ham	3.1	2.4/1.7	[71]
Salami	11.7	9.8/6.3	[71]
Bread	2.0	1.8/1.61/1.38	[72]
Cottage cheese cream	2.2	1.48/0.73	[73]
Pizza crust	1.09	1.02/0.99/0.91/0.84/0.76/0.51	[52]
Cheddar cheese	1.8–2.1	1.25/0.50	[74]
Prato cheese	1.68	1.23	[75]
Cooked ham	1.9	1.33/0.95/0.00	[76]
Soup	0.3/0.2/0.1	0.21/0.14/0.07	[77]
Dried fish	10	5	[78]
Durum wheat bread	2.0	1.5/1.0	[79]
"*Painho de Portalegre*"	6.0	3.0/2.0	This study

Table 1.
Salt reduction studies in different food products.

The effect on consumer acceptance or consumer perception of low-salt foods has been evaluated, and these studies should precede the development of new products by the food industry [81].

Table 2 summarises some recent studies on salt replacement, considering different food products.

As it can be seen from **Table 2**, there are numerous salt replacement studies on bread and meat products, whereas only a few on other foods.

Regarding bread and other bakery products, potassium chloride has a lower inhibiting effect on the yeast. Furthermore, proofing and mixing times are shorter. Moreover, potassium chloride is more difficult to dissolve in water than sodium chloride. Hence, it is important to choose "fine" potassium chloride and not a coarse grade. The undissolved grains will cause dark brown spots on the crust of the product. Still, KCl showed characteristics similar to NaCl in baked products. However, other salt replacers, such as magnesium chloride, ammonium chloride, magnesium sulphate or calcium chloride, have limited application due to their more unpleasant flavour [97].

Aromatic and medicinal plants (AMP) can also be used as flavouring agents, giving a tastier flavour to foods and thus enabling salt reduction [98]. Herbs or AMP, namely, oregano, basil, marjoram, thyme and bay leaf, added to fresh soups, reduced the need for salt intake when the perceived herb flavour increased [87]. Spices have also been added to dried fish goldstripe sardinella (*Sardinella gibbosa*) to reduce the amount of added salt [78].

Salicornia sp. is a wild food plant with long history of human consumption that has been used in traditional vegetable mixtures in Italy [99] and is known for its salty taste and high nutritional values [100].

Food product	Salt substitute	Reference
Cooked ham	KCl	[76]
Dry-fermented sausages	KCl	[82]
Fermented sausages	KCl/potassium lactate/glycine	[83]
Dry-cured pork loin	KCl/potassium lactate/glycine	[83]
Dry-fermented sausages	Calcium ascorbate	[84]
Pork sausage patties	KCl	[85]
Dry-fermented sausages	$KCl/CaCl_2$	[86]
Fresh and canned soups	Herbs	[87]
Bread	KCl/yeast extract	[88]
Bread	$CaCl_2/CaCO_3$	[89]
Wheat bread	$KCl/MgCl_2/CaCl_2$	[90]
Brown bread	Calcium carbonate/$MgSO_4/MgCl_2$/KCl	[91]
Cheddar-style cheese	$KCl/MgCl_2/CaCl_2$	[92]
Mozzarella cheese	KCl	[93]
Pizza crust	KCl	[52]
White bread	$CaCl_2/MgCl_2/KCl/MgSO_4$	[94]
Fermented sausages	KCl	[95]
Dry-cured loins	KCl	[96]
Slow-fermented sausages	KCl	[15]
Cooked ham	KCl	[76]

Table 2.
Salt replacement studies in different food products.

5.1 Meat and meat products

Several studies have reported the reduction of salt content in meat products and its partial replacement with other salts, such as potassium chloride (KCl), magnesium chloride (MgCl), lithium chloride (LiCl), calcium chloride ($CaCl_2$) and phosphates [101].

However, concerning dry-cured meat sausages, it is more difficult to develop low-salt traditional products. Sodium chloride has a determinant effect both in flavour as in the microbiological stability of sausages.

Gou et al. [83] used potassium chloride, potassium lactate and glycerine as partial substitutes for sodium chloride in the formulation of fermented sausages. However, major defects were found regarding aroma and flavour when these salts replaced more 40% of the sodium chloride content. These authors also found changes in texture when the NaCl was replaced by potassium lactate at levels above 30% or by glycine at levels 50%.

Ibáñez et al. [82] detected the development of nitrosamines and the heterofermentative activity of carbohydrates by starter cultures were favoured by a mixture of 1.37% NaCl and 0.92% KCl, when compared to the same sausages manufactured with 2.73% NaCl.

Other studies have shown a sensory depreciation in sausages with 1% NaCl, 0.55% KCl, 0.23% $MgCl_2$ and 0.46% $CaCl_2$, when compared to sausages with 2.6% NaCl [84]. A significant reduction in the sodium content of Spanish sausages was

Microbiological groups (cfu/g)	Salt content (% NaCl)	
	2%	3%
Total mesophiles	7.44	7.93
Total psychrotrophic microorganisms	7.25	7.85
Yeasts	2.60	4.28
Moulds	n.d.	n.d.
Gram-positive, catalase-positive cocci (GCC+)	6.59	5.38
Lactic acid bacteria (LAB)	8.46	8.41
Enterobacteria	3.21	2.90
Enterococci	5.86	5.66
Spores of aerobic bacteria*	3.11	3.98

n.d., none detected
**Expressed in number of spores/g.*

Table 3.
Microbiological analyses of traditional Portuguese dry-fermented sausages (Painho de Portalegre) with low-salt content.

achieved by the partial replacement of NaCl by different percentages of calcium ascorbate [86]. However, these sausages showed worse results for colour and texture when compared with control sausages.

Regarding microbiological parameters, no unwanted changes were noticed with the replacements of NaCl by other salts, in all the above-mentioned studies. From a sensory point of view, the major advantage of these sausages seems to be the insufficient salty flavour.

In a study regarding the microbiological, physicochemical, biochemical and sensory characteristics of traditional sausages from Alentejo, Portugal (*Painho de Portalegre*), instead of replacing NaCl, the authors reduced its content to 3% in the final product. The influence of salt content (2 or 3% NaCl in the final product) on the microbiota and the rheological and sensory properties of sausages were evaluated, and the results are shown in **Table 3**.

The number of mesophiles did not vary significantly, although the sausages with 3% NaCl have slightly higher counts. These results seem to indicate that the natural microbiota of these sausages is characteristically halotolerant. This is even more evident for yeasts. On the other hand, the counts of enterobacteria and enterococci are higher in 2% NaCl sausages. Considering that these microbiological groups are associated with the hygiene conditions of the manufacturing process, the bacteriostatic role of salt was beneficial. As for the technological microbiota [102, 103], the lactic acid bacteria, still present in high numbers in the final product, which is characteristic in this kind of sausage, almost do not vary with the sodium chloride concentration. Interestingly, Gram-positive, catalase-positive cocci (GCC+) show higher counts in the 2% sausages, although they usually grow well in the presence of salt [104]. The counts of all other microbial groups did not vary with salt content.

Regarding sensory analysis (**Table 4**), sausages with 2% NaCl showed higher colour intensity values, but 3% NaCl sausages were tender (confirmed by the rheological tests), more succulent and with higher flavour intensity. The results obtained for these two last attributes may be because salt stimulates salivation and potentiates the flavour of foods. Concerning global appreciation, there was a slight preference for the sausages with less salt.

Generally, the microbiota of these sausages did not vary with salt content. Furthermore, concerning sensory analysis, no significant differences were observed

Sensory attributes	Salt content (% NaCl)	
	2%	3%
Colour intensity	75.6 ± 9.3	61.8 ± 18.2
Aroma intensity	69.4 ± 12.3	65.0 ± 8.8
Tenderness	65.0 ± 16.6	74.6 ± 14.5
Fibrousness	31.4 ± 22.1	29.8 ± 19.9
Succulence	66.75 ± 9.7	70.0 ± 10.0
Flavour intensity	67.6 ± 10.5	72.2 ± 5.3
Off-flavours	5.2 ± 8.4	8.0 ± 13.0
Salt intensity	56.0 ± 9.0	64.0 ± 11.4
Global appreciation	71.2 ± 11.2	69.0 ± 6.5

Data are expressed as means ± standard deviation.

Table 4.
Sensory analysis of traditional Portuguese dry-fermented sausages (Painho de Portalegre) with low-salt content.

for any of the studied attributes. Furthermore, the rheological analysis showed no influence of salt content in the studied attributes.

Furthermore, the production of *Painho de Portalegre* is characterised by a different formulation regarding salt content. These may significantly influence the qualitative and quantitative formation of biogenic amines, since they modulate the microbiota throughout the manufacturing process. Thus, regarding the profile in biogenic amines, differences were detected between the two salt concentrations.

In another study with *Painho de Portalegre*, the effect of salt in the profile of biogenic amines was evaluated. Differences were observed between the two salt concentrations in the final product, 3 and 6% NaCl (data not shown). The content in biogenic amines, mainly cadaverine, putrescine, tyramine and β-phenylethylamine, was severely reduced in 6% NaCl sausages throughout the curing period.

Several other studies on traditional Portuguese sausages have shown the neutral or positive effect of salt reduction on these products.

Salt reduction does not negatively affect the quality and acceptability of sausages [105].

Sensory evaluations revealed that despite the less intense aroma, products with 3% salt had a more balanced salt perception. Our results suggest that salt content may be reduced to 50% in dry-cured products, with the obvious health-related advantages [70].

Low-salt sausages were clearly preferred by panellists [69].

The reduction in salt content from 6 to 2% in large calibre pork sausages did not compromise safety nor depreciate the sensory acceptability of the products [106].

Coutron-Gambotti et al. [107] studied the effect of salt reduction on the lipidic composition and sensory attributes of dry-cured ham and observed a reduction in the number of autoxidation processes and a consequent improvement of aroma and flavour. Regarding rheological analysis, salt content did not significantly influence the textural characteristics of the sausages, namely, hardness, cohesiveness, elasticity, gumminess, chewiness and shear force.

Regarding consumer acceptance studies, low-salt small calibre fermented sausages with a NaCl/KCl 50:50 ratio were found to be acceptable for consumers [95]. Moreover, dry-cured loins also with a 50:50 ratio NaCl/KCl obtained the highest scores in sensory evaluation by a trained panel [96].

Tamm and co-workers [76] produced low-salt cooked hams (30% reduction) without significant differences in water binding and texture compared to regular-salt hams, by combining the use of a high isostatic pressure treatment with the partial replacement of NaCl by KCl.

5.2 Bread and bakery products

Bread is a major contributor to sodium intake. Therefore, a reduction in the salt content of bread would cause a great impact on global health.

Recently, there has been quite some pressure on the bakery sector to reduce the salt content in bread, cakes and muffins, among others. Potassium chloride has been regarded as an acceptable substitute for sodium chloride as it has basically the same rheological effects on the dough. However, if sodium chloride is replaced by the same amount of potassium chloride, the bread will have a bitter aftertaste. This is only a problem in bread; it does not occur in products such as muffins or cakes, because this aftertaste mostly disappears after 2 or 3 days and it can be masked using eggs and butter.

Reduction of salt in bread involves changes in quality characteristics, such as flavour, shelf life and texture. Besides, the manufacturing process is affected by changes in dough stickiness [40]. The replacement of NaCl by KCl does not have any significant processing disadvantages but has a negative impact on flavour [40].

Several studies have evaluated the acceptable replacement levels of NaCl by KCl in bread [108, 109].

5.3 Other food products

Strategies for reducing "salt" in cheese include mainly the reduction of table salt (NaCl) and its replacement by potassium chloride (KCl). However, these strategies present many challenges, such as adverse effects on flavour, microbiological stability and functional properties of the final product. When salt content is simply reduced in natural cheese, proteolysis, water activity, acidity and bitterness all increase, while hardness decreases. In addition, irregular fermentations could occur which may alter the desired characteristic taste of the cheese, namely, the development of a bitter unacceptable flavour.

In cheddar cheese, which has been extensively studied with respect to salt reduction, analysis showed that reducing NaCl resulted in an unpleasant aftertaste and bitterness. Within a range of 0.5–3% salt, at salt levels below 1.5% compared to higher levels of 1.8–3%, an increase in the growth of undesired non-starter bacteria occurred that caused bitter flavours due to excessive proteolysis [74].

The reduction and/or replacement of sodium chloride (NaCl) by potassium chloride (KCl) in cheese is a difficult task that may affect the global desired quality of the cheese. It depends, among other factors, on the type of cheese. The different manufacturing processes make it easier to reduce or replace table salt in processed cheeses than in natural or soft cheeses [110].

The reduction of salt levels in cheese can be done over a period of time, to prevent the consumer from detecting organoleptic changes [111].

NaCl reduction in cottage cheese cream dressing is possible from a mechanical or rheological point of view, without significantly changing the sensory acceptability of the product [73].

Processed foods, namely, those with a high salt content for preservation, such as pickles, smoked foods, concentrated broths and meat-based food, namely, patties, croquettes, sausages and ham, canned seafood, fish and meat, dried or salted codfish, crackers and industrial sauces, are responsible for most of the salt consumed. Therefore, when cooking and eating at home, consumers should avoid these foods.

Potential effect of salt reduction in processed foods has been reviewed [112].

Pizza is a major contributor to the daily sodium intake [52]. Mueller and co-workers prepared pizza crusts with reduced sodium contents of up to 25%, without depreciating their sensory evaluation [52].

Ready-to-eat foods to take away or served in restaurants also contribute immensely to the salt intake of the modern consumer. Ahuja and colleagues [60] reviewed the subject and emphasised the importance of public health efforts together with food manufacturers and restaurants to reduce the sodium levels in prepared meals.

6. World policy, particularly in the European Union

The WHO has made several policy recommendations to reduce salt intake, restrict or eliminate choice, guide choice through (dis)incentives, enable or guide choice through changing default (reformulation and marketing), restrict or eliminate choice, provide information (public health campaigns and labelling) and monitor. These may be combined to effectively reduce salt consumption [113].

Likewise, some policy approaches have already been implemented, which mainly pursue the objectives: to provide information, to make the healthy option available or to provide financial (dis)incentives related to salt consumption [113]. Several governments from countries around the world have adopted national salt reduction strategies, which range from legal obligations, such as the limit of salt content in bread, to intended actions involving the food industry, mainly regarding reformulating of food products [13].

Food product	Country	Salt level (%)	Reference
Bread	Austria	15% reduction	[114]
Bread	Belgium	<2%	[114]
Bread	Bulgaria	<1.2%	[115]
White cheese in brine	Bulgaria	<3.5 ± 0.5%	[115]
Yellow cheese "Kashkaval"	Bulgaria	1.8–3.0%	[115]
Durable boiled smoked sausage	Bulgaria	≤3.5%	[115]
"Lutenica"*	Bulgaria	≤1.7%	[115]
Bread	Croatia	30% reduction in added salt	[114]
Bread	Finland	Low-salt threshold: 0.7%	[114]
Sausages	Finland	Low-salt threshold: 1.2%	[114]
Cheese	Finland	Low-salt threshold: 0.7%	[114]
Fish products	Finland	Low-salt threshold: 1%	[114]
Breakfast cereals	Finland	Low-salt threshold: 1%	[114]
Butter	Finland	Low-salt threshold: 1%	[114]
Soups	Finland	Low-salt threshold: 0.5%	[114]
Sauces	Finland	Low-salt threshold: 0.5%	[114]
Ready-made dishes	Finland	Low-salt threshold: 0.5%	[114]
Crisp bread	Finland	Low-salt threshold: 1.2%	[114]

Food product	Country	Salt level (%)	Reference
Bread products	Finland	Heart symbol: <0.28% sodium	[114]
Bread	Greece	<1.5%	[115]
Tomato juice	Greece	<1%	[115]
Concentrated tomato puree paste	Greece	<4%	[115]
Biscuits	Greece	<0.5% sodium	[115]
Bread	Hungary	16% reduction	[114]
Various food products	Ireland	"Reduced salt" status: >25% reduction	[114]
Bread and bakery	Italy	10–15% reduction	[114]
Food served in schools	Latvia	<1.25 g salt/100 g	[114]
Food served to children	Lithuania	<0.4 mg sodium/100 g	[114]
Bread	Netherlands	<1.8%	[114]
Bread	Portugal	<1.4%	[114]
Food served in schools	Romania	<1.5%	[115]
Food served in schools	Romania	<0.6% sodium	[115]
Bread	Spain	26.4% reduction	[114]
Bread	UK	<1.0–1.2%	[115]
Bread	UK	<0.6% sodium	[116]
Bread	Turkey	<1.4%	[114]
Bread	Argentina	<0.6% sodium	[116]
Bread	Brazil	<0.6% sodium	[116]
Bread	Canada	<0.6% sodium	[116]
Bread	Chile	<0.6% sodium	[116]
Soup	Argentina	<0.36% sodium	[116]
Soup	Brazil	<0.36% sodium	[116]
Soup	Canada	<0.36% sodium	[116]
Breakfast cereals	Canada	<0.63% sodium	[116]
Breakfast cereals	Chile	<0.63% sodium	[116]
Cooked, uncooked, processed meats/sausages	Argentina	<1.21% sodium	[116]
Cooked, uncooked, processed meats/sausages	Brazil	<1.21% sodium	[116]
Cooked, uncooked, processed meats/sausages	Canada	<1.21% sodium	[116]
Dry-cured meats and meats conserved at RT	Argentina	<1.9% sodium	[116]
Dry-cured meats and meats conserved at RT	Brazil	<1.9% sodium	[116]
Dry-cured meats and meats conserved at RT	Canada	<1.9% sodium	[116]
Mayonnaise	Brazil	<1.05% sodium	[116]
Mayonnaise	Canada	<1.05% sodium	[116]

Food product	Country	Salt level (%)	Reference
Mayonnaise	Chile	<1.05% sodium	[116]
Cookies and sweet biscuits	Argentina	<0.485% sodium	[116]
Cookies and sweet biscuits	Brazil	<0.485% sodium	[116]
Cookies and sweet biscuits	Canada	<0.485% sodium	[116]
Cookies and sweet biscuits	UK	<0.485% sodium	[116]
"Mozzarella" cheese	Brazil	<0.559% sodium	[117]
Various food products	USA	"Healthy claim": <1.1 mg sodium/kcal	[60]

**Processed tomato and vegetable mixture; RT, room temperature.*

Table 5.
Policy on salt reduction per food product in different countries.

In 2013, the salt reduction initiatives in the WHO European Region have been mapped and described by country [114]; however, the progression has been slow, and salt intake in most WHO European Region countries is far above the suggested amount [18]. Some countries adopted initiatives to reduce the total amount of salt consumed (maximum daily intake), others the amount of sodium, but only a few legislated the amount of salt added to food products and mainly to bread [60, 114–117].

In Portugal, an agreement was signed on May 2, 2019, between the *General Directorate of Health*, a central department of the Ministry of Health, and seven food industry and food distribution associations, to reduce the content in salt, sugar and *trans* fats in over 2000 food products, for a healthier diet [118].

In a study conducted in the USA with processed and restaurant foods, more than half of the analysed foods exceeded the US Food and Drug Administration's (FDA) sodium limit for using the claim "healthy" [60]. This "healthy" claim reports to the Healthy Eating Index-2010 [119] and to an optimal sodium level below 1.1 mg/kcal.

Systematic reviews on salt reduction initiatives in different countries around the world have been published previously [12, 13].

A non-exhaustive summary of the current national initiatives per food product comparing policies between different countries, mainly of the European Union, is shown in **Table 5**.

7. Conclusions

Salt (sodium chloride) has played different but very important roles throughout human history. It has been an important product, firstly for its action in food preservation and for its role as flavour enhancer. More recently, the effect of salt on some food components, namely, proteins, has also been recognised. In fact, salt modifies the structure of proteins and their interaction with other food components, which has consequences on the technological properties of those food products (meat and meat products, bread and other bakery products, cheese and other dairy products and canned fish products, among others). Regarding the technological role of salt, it also has an evident effect on microbial modulation, which is particularly important in fermented products and regulating the enzymatic activity.

This fundamental role of salt has been an obstacle to the reduction of its consumption, the latter being related to the occurrence of consumer health problems, namely, cardiovascular diseases. Adapting ourselves and training our taste to the flavour of low-salt food is undoubtedly the best way to assure the reduction of salt consumption. For the above-stated reasons, the WHO recommends a daily salt intake of 5 g per day for adults. Following these recommendations, several countries have implemented distinct measures to reduce the consumption of salt in different food products. Furthermore, numerous studies have been performed to find adequate alternatives to replace salt.

Nevertheless, some recent studies have unravelled that the negative effect of salt in human health has been systematically supported by trials, whose target groups were more susceptible to salt intake, such as hypertense, malnourished or elderly people. Therefore, new studies with healthy groups are needed. Moreover, there are recent studies that suggest the need to evaluate the intake of sodium and potassium comparatively, because potassium seems to have a beneficial effect in preventing hypertension, one of the predispositions for cardiovascular diseases. To cite Chris Kresser [120], it is important to question ourselves and "shake up the salt myth".

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Conflict of interest

The authors declare that they have no conflict of interest.

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