SALT CONSUMPTION, HEALTH IMPLICATIONS AND TECHNOLOGICAL CHALLENGES OF SODIUM REDUCTION IN FOODS

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Abstract

Sodium is an essential nutrient, but in most populations its intake, mainly as sodium chloride, is about twice the World Health Organization recommendation of less than 5 g salt/day, which contributes to hypertension and cardiovascular disease. This review summarises the health effects of excessive salt intake, the main dietary sources of sodium, the functions of salt in bread, meat products and cheese, and the strategies available for reducing it. Because salt contributes to flavour, texture, water binding and microbial safety, its reduction must be adapted to each product and validated for safety and shelf life. Gradual reduction, partial replacement with potassium salts (up to about 30%), flavour enhancers and changes in salt crystal size or distribution can lower sodium by 25 - 50% without loss of acceptability. Reformulation is most effective when combined with clear labelling, consumer education and public policies.

Key words*: hypertension, reformulation, flavour enhancers, microbial safety, consumer education*

INTRODUCTION

Sodium is the main cation of the extracellular fluid and an essential nutrient. It regulates extracellular and plasma volume, determines the membrane potential of cells and takes part in the active transport of molecules across cell membranes; about 98% of dietary sodium is absorbed in the intestine, and the excess is excreted mainly by the kidneys [1]. Approximately 90% of the sodium in the diet comes from table salt (sodium chloride, NaCl), and because salt is added to so many products and dishes, dietary sodium deficiency is very rare, whereas excessive intake is a frequent problem [2]. For thousands of years salt was regarded as a preservative that protected human health by limiting the growth of pathogens and spoilage microorganisms; with the growing consumption of processed foods, it is now increasingly seen as a potential health threat [1].

The World Health Organization (WHO) recommends less than 2000 mg sodium/day for adults, equivalent to less than 5 g salt/day [3, 4]. Nevertheless, in almost all countries intake exceeds this level, and high sodium intake has become one of the leading dietary risk factors for non-communicable diseases, being associated with an estimated 1.89 million deaths each year [2, 5, 6].

Reducing sodium in foods is not simply a matter of removing salt. NaCl is a multifunctional ingredient that determines saltiness and overall flavour, contributes to structure formation, water binding and processability, and acts as a hurdle against microbial growth, thus influencing safety and shelf life [1, 6]. The aim of this review was to synthesise the current knowledge on the health implications of excessive salt intake, the main dietary sources of sodium,

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the technological functions of salt in the main food categories and the technical and policy strategies available for sodium reduction.

MATERIAL AND METHOD

This paper is a narrative review of the scientific literature. The documentation was based on review papers dealing with sodium intake, its health effects and sodium reduction in foods [1, 2, 6], on the original research articles cited in these reviews and on reports and guidelines of the WHO [3, 4]. Priority was given to papers published in international peer-reviewed journals and, where possible, to recent publications.

The information was selected according to its relevance to the topic and was organised in five directions: (i) sodium intake and its impact on health; (ii) the dietary sources of sodium; (iii) the technological functions of salt in foods; (iv) the challenges and results of salt reduction in bread, processed meat, cheese and ready meals, together with the technical solutions available; and (v) consumer perception and public health policies for sodium reduction. The data taken from different sources were compared and summarised in figures and tables.

RESULTS AND DISCUSSION

Sodium intake. The global mean intake is estimated at 4310 mg sodium/day (10.78 g salt), more than double the WHO recommendation [2, 4]. On average, adults consume about 9 - 10 g salt/day and children and young people about 7 - 8 g/day [2]. Regional estimates range from 2687 mg sodium/day in the African Region to 6247 mg/day in the Western Pacific Region, and all WHO Member States exceed the recommended level [2]. In European countries, women consume 7.3 - 10 g salt/day and men 9.4 - 13.3 g/day, i.e. 1.5 - 2.7 times the recommended amount [2]. As shown in Fig. 1, Romania, with about 5075 mg sodium/day, is among the countries with the highest reported intake, close to Hungary, Czechia, Bulgaria and Croatia [2, 4].

Health effects. Excessive sodium intake is a well-established cause of raised blood pressure and increased risk of cardiovascular disease (CVD) [2]. Salt is also listed among the foods that should not be consumed in excess, as high intakes are harmful to health, with a recommended intake of no more than 2 - 3 g/day [7]. In salt-sensitive persons, a lower capacity to excrete the excess sodium may lead to an expansion of plasma volume and a sustained increase in vascular resistance [1]. The INTERSALT study, carried out in 52 centres from 32 countries, confirmed the correlation between urinary sodium excretion and blood pressure, and populations with very low sodium intake had low blood pressure that did not increase with age [1, 2]. A meta-analysis of dietary interventions lasting at least one month showed a clear dose-response relationship: a reduction of 6 g salt/day lowered systolic blood pressure by about 7 mmHg in hypertensive and 4 mmHg in normotensive subjects [1, 8].

Sensitivity to sodium differs between individuals. It is more frequent in people with hypertension (30 - 50% of cases, compared with 15 - 25% in normotensive people), in obese, diabetic and elderly persons and in people with metabolic syndrome, while genetic factors also influence individual sensitivity [2]. Besides hypertension, high salt intake has been associated with gastric cancer [9, 10], progression of kidney disease, kidney stones and increased urinary calcium losses; about 26 mg of calcium is excreted for each gram of sodium consumed, which may affect bone health when calcium intake is low [1, 2]. On the other hand, very low intakes (below about 1500 mg sodium/day) are not recommended for some high-risk groups, such as people with heart failure or kidney disease, so the aim is a moderate and balanced intake [2].

Dietary sources of sodium. Only about 10% of dietary sodium occurs naturally in

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foods. In Europe and North America, 5 - 10% is added at the table and during cooking, while processed foods and meals eaten outside the home contribute over 75% of the intake [1, 6, 11]. This is supported by the growing demand for semi-prepared and ready-to-eat products, preferred especially by busy urban consumers for their speed of preparation and affordable price [12]. Bread and cereal products provide 35 - 50% of sodium intake in some countries, because they are eaten daily and in large amounts, and processed meat products contribute another 20 - 30% [1, 2, 13]. Food processing strongly increases the salt content compared with the fresh raw materials, as in the case of canned beans, sauerkraut, ketchup, prosciutto or feta cheese, and fast foods are particularly salty: a typical lunch consisting of a sandwich with chips and ketchup provides about 4.5 g salt, i.e. 90% of the recommended daily amount [2]. In Asian countries, by contrast, salt and sauces added during cooking account for 72 - 76% of the intake [1], and in Czechia, Poland and Romania salt added during cooking also remains the most important source of sodium [2].

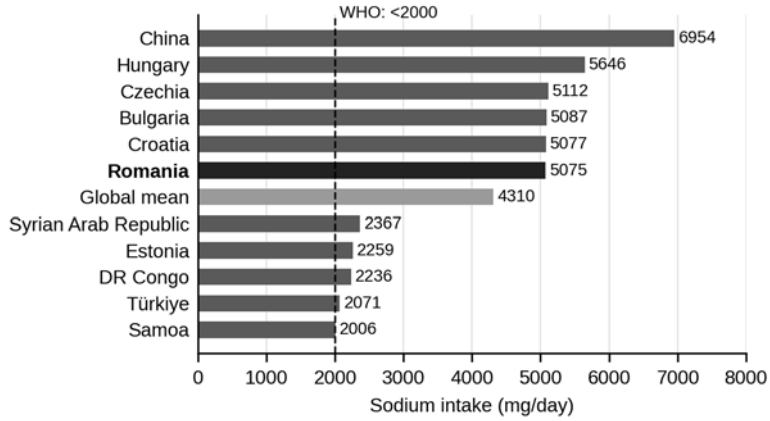


Fig. 1 Estimated mean sodium intake in selected countries compared with the WHO recommendation of less than 2000 mg sodium/day (data from [2, 4])

Functions of salt in foods. Saltiness is one of the basic tastes, and sodium and lithium are the only cations with a mainly salty taste; potassium and calcium also have bitter or metallic notes [1]. Besides saltiness, NaCl enhances the flavour of other ingredients and suppresses bitterness, so reducing it can make foods taste bland and reveal bitter notes [6]. Since about 25% of the population are supertasters, very sensitive to bitter compounds, a marked salt reduction may make some foods unpalatable for a quarter of consumers, while another quarter may not notice the change [1]. Salt also controls texture: in meat products, 1.5 - 2.5% added salt solubilises the myofibrillar proteins, which increases water and fat binding and allows the formation of heat-stable emulsions, whereas comminuted products with less than 1.5% salt form unstable emulsions with poor texture [1, 6]. In bread dough, salt strengthens the gluten network that retains gas bubbles and controls yeast activity and fermentation rate [1, 6].

From a microbiological point of view, salt lowers water activity (a_w) and acts as one of the hurdles that together ensure the safety of foods [6, 14]. Most bacteria, including many pathogens, grow only at a_w values between 1 and 0.95, while yeasts and moulds tolerate values as low as ~0.7 [6]. Microorganisms differ widely in salt tolerance: *Campylobacter* is very sensitive,

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whereas *Listeria monocytogenes* remained viable for 259 days at 4 °C in a commercial cheese brine with 23.8% NaCl [1]. Salt usually works in combination with other preservatives; for example, in broth at 10 °C, 5.5% NaCl was needed to slow the growth of *L. monocytogenes* in the absence of nitrite, whereas 120 ppm nitrite combined with only 0.5% NaCl had a similar effect [1]. Other sodium-containing additives (lactate, phosphates, nitrite, benzoate) also contribute to the sodium content; sodium lactate alone may provide 310 - 620 mg sodium/100 g of food [1]. Therefore, every reduction in salt requires a case-by-case re-evaluation of microbial safety and shelf life, and the loss of preservative effect may have to be compensated by other hurdles such as heat treatment, high-pressure processing, modified atmosphere packaging, organic acids or strict refrigeration [1, 6]. This aspect is particularly critical in raw and processed meat matrices, where the persistence and control of pathogenic strains remain a major safety challenge [15].

Bread and cereal products. Because of the quantities consumed, bread is the main target for reformulation [2, 16]. An adult eating 250 g of bread with 1.2% salt consumes 3.0 g salt, i.e. 50% of the reference intake of 6 g/day [2]. The European Commission recommends 1.0 - 1.2% salt relative to flour and the WHO benchmark for yeast-leavened bread is 330 mg sodium/100 g, but the average salt content of bread still varies widely between European countries (Table 1) [2]. Reducing salt in wheat bread from 1.2% to 0.6% or 0.3% did not significantly affect dough rheology, baking quality or sensory attributes, whereas complete omission produced unpleasant flavours and poorer structure [17]. Partial replacement is also possible: a brown bread containing 32% less sodium, formulated with KCl, calcium carbonate, magnesium chloride and magnesium sulphate, had acceptable baking properties and flavour [18]. In pizza crust, sodium could be reduced by 10% in a single step or 30% of NaCl could be replaced with KCl without a noticeable loss of saltiness, and spraying a salt solution on one side of the crust reduced the total salt by 25% [19].

Table 1 Average salt (NaCl) content of bread in selected European countries

Country	Average NaCl content in bread (%)
Germany	1.6
Poland	1.64
Italy	1.5
Netherlands	1.19
Switzerland	1.0
United Kingdom	0.95
Latvia	0.8 - 1.2
Ireland	0.6 - 1.68

Note: NaCl - sodium chloride. The European Commission recommends 1.0 - 1.2% salt relative to flour. Data compiled from [2].

Processed meat. Fresh meat contains little sodium, but processed meat usually contains about 2% added salt and dry products up to 6% [13]. In meat products, the excessive use of salt in association with other treatments, such as smoking or the addition of chemical additives, may be associated with health risks [20]. Consumers increasingly ask for products with less salt, fat and nitrite, and salt reduction targets have

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been set for several meat products, e.g. 1.63 g/100 g for ham in the United Kingdom [21]. Studies on hot dog sausages, bacon, ham and salami showed that salt reduction affects both sensory quality and microbial growth [22]. A sensory-driven approach in corned beef achieved a 60% sodium reduction using potassium lactate and glycine, without a negative impact on the microbiological shelf life of the modified-atmosphere-packed product, although the product was perceived as less salty [23]. In fermented cooked sausages, the undesirable sensory effects of replacing 50% and 75% of NaCl with KCl were masked by adding monosodium glutamate, disodium inosinate, disodium guanylate, lysine and taurine [24]. Replacing regular salt with micronized salt allowed a 33% reduction (from 1.5% to 1.0%) in beef burgers without decreasing perceived saltiness [25]. Non-meat components also contribute to the salt content: in semi-prepared chicken fillet products, salt ranged from 0.8 to 1.3 g/100 g depending only on the type of coating, being highest with a composite corn flake crust and lowest with a pumpkin seed crust [26].

Cheese, ready meals and sauces. Salt levels in natural cheeses range from 0.7% to 6% and influence moisture, water activity, starter and enzyme activity, proteolysis and, therefore, flavour and texture [1, 27]. Salt reduction generally increases moisture, water activity and proteolysis, which can lead to pasty texture and off-flavours [27]. Nevertheless, a 25% salt reduction in Prato cheese did not affect proteolysis or sensory acceptance [28], and partial substitution of KCl for NaCl does not affect starter culture activity, whereas magnesium and calcium chlorides make cheese crumbly, soft or greasy [1]. In ready meals, the salt content of a chicken curry could be reduced from 0.6% to 0.4% without a detectable difference in saltiness, and to 0.2% when salt replacers were added [21]; naturally brewed soy sauce allowed a reduction of 0.2 - 0.25% NaCl in salad dressing, soup and stir-fried pork without loss of saltiness [29]. In sauerkraut, the use of a *Leuconostoc mesenteroides* starter culture allowed a good product to be obtained with only 0.5 - 1% salt instead of the usual 2 - 2.25% [1].

Technical solutions. The strategies available for sodium reduction are summarised in Table 2. The simplest is gradual reduction: steps of 5 - 10% are usually not noticed by consumers [1, 30], and salt taste receptors adapt to lower concentrations within 4 - 6 weeks, after which consumers prefer less salty foods [2]. Potassium chloride is the most common replacer, but above about 30% replacement it induces bitterness and a metallic taste [1, 31]; more than 80% of consumers could not distinguish regular salt from potassium-enriched substitutes containing less than 30% KCl [2]. At population level, low-sodium salt substitutes reduced systolic and diastolic blood pressure by 7.81 and 3.96 mmHg, respectively [32], but they may increase the risk of hyperkalaemia in people with impaired potassium excretion, such as those with chronic kidney disease [2]. Other approaches act on perception: flavour enhancers such as monosodium glutamate, yeast extracts, organic acids and some amino acids, as well as congruent aromas, herbs and spices, can increase perceived saltiness, and salt can be delivered faster or unevenly to the taste receptors by using smaller crystals, encapsulation, layered structures or double emulsions [2, 6, 33]. For example, inhomogeneous distribution of salt in bread reduced sodium by about 30% while perceived saltiness actually increased [34]. Most of these solutions are product-specific, and their combination can maximise the reduction [6].

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Table 2 Technical solutions for sodium reduction in foods

Strategy	Principle	Examples of results	Main limitations
Gradual (stealth) reduction	Successive small reductions allow taste receptors to adapt	Steps of 5 - 10% not noticed; 20 - 30% reduction in UK brands over 3 years without effect on sales	Slow; limited by the technological functions of salt
Partial replacement with other salts	Exchange of part of NaCl with KCl, $CaCl_2$, $MgCl_2$, $MgSO_4$ or potassium lactate	Brown bread with 32% less sodium; corned beef with 60% less sodium	Bitter and metallic taste above ~30% KCl; hyperkalaemia risk in kidney disease
Flavour enhancers and multisensory combinations	Umami (MSG, yeast extracts), congruent aromas, herbs and spices increase perceived saltiness	30 - 40% reduction in soups with MSG; 0.2 - 0.25% less NaCl with soy sauce	Aroma stability during processing; congruency with the product
Salt particle size and form	Smaller or hollow crystals dissolve faster in saliva	33% reduction (1.5 to 1.0%) in beef burgers with micronized salt	Rapid loss of saltiness after chewing; dissolution in the food matrix
Encapsulated (coated) salt	Fat coating delays dissolution until mastication	0.7% large coated crystals as salty as 1.0% table salt in beef patties	Higher cooking loss; denser bread; few commercial products
Inhomogeneous salt distribution	Taste contrast between high- and low-salt zones enhances saltiness	~30% reduction in layered bread; 25% reduction in pizza crust	Salt migration during processing and storage; industrial feasibility
Microstructure design (double emulsions, serum release, brittleness)	Control of the amount of sodium reaching the taste receptors	Juicier sausages perceived as saltier	Emulsion stability; product-specific solutions

Note: KCl - potassium chloride; $CaCl_2$ - calcium chloride; $MgCl_2$ - magnesium chloride; $MgSO_4$ - magnesium sulphate; MSG - monosodium glutamate. Compiled from [1, 2, 6, 18, 19, 23, 25, 34].

Consumer perception. Knowledge alone does not guarantee lower salt intake. People generally know that they eat too much salt but are not aware that they exceed the recommendation more than twice, and in one study 86% of patients knew that excessive salt is harmful but only 44% believed that it was worth reducing it [2]. In Ireland, more than 90% of consumers were aware of the health risks of a diet high in salt and fat, but fewer transferred this knowledge into their diet; nevertheless, 43% reported buying more reduced-salt foods [35]. Adapting food formulations and ensuring strict quality control are essential steps when designing safer, nutritionally optimized products tailored to vulnerable or health-conscious consumer segments [36]. At the same time, consumers want clean labels, short ingredient lists and long shelf life, expect reduced-salt products to keep the taste they are used to and may resist changes in traditional products [6, 37]. Front-of-pack labelling can help consumers make healthier choices, but insufficient knowledge on label interpretation and the lack of sodium information on many labels limit its effect [2]. Consumer education is therefore needed not only on the recommended intake, but also on the "hidden" salt in bread, processed meat and cheese and on the salt added at home, which is particularly important in countries such as Romania [2].

Public health policies. Food reformulation must be supported by public policies. The WHO recommends four measures for sodium reduction: reformulation of foods with target levels for salt, supportive environments in public

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institutions such as schools, hospitals and workplaces, front-of-pack labelling and mass media campaigns [4, 21]. Long-term programmes have proved effective. In Finland, salt intake among men decreased from 12 - 13.2 g/day in 1979 to 8.6 - 9.5 g/day in 2002, while mean systolic blood pressure fell by about 8 mmHg [1, 38]. In the United Kingdom, voluntary targets for 76 food categories reduced the salt content of many products by 40 - 50%, although mean intake remains 8.1 - 8.8 g/day [2, 39]. Hungary introduced in 2011 a tax on salty snacks (>1 g salt/100 g) and seasonings (>5 g/100 g), which led to reformulation of many products and a 26% decrease in the sales of salty snacks, and in South Korea sodium intake fell from 4586 mg/day in 1998 to 3255 mg/day in 2018 [2]. Nevertheless, no country has yet achieved the global target of a 30% relative reduction in salt intake by 2025 [2, 40]. Romania has adopted mandatory sodium declaration on pre-packed foods and at least one mandatory measure for sodium reduction [4, 21], but reformulation targets for the most consumed products and education campaigns on salt used in home cooking could further increase the impact of these measures.

CONCLUSIONS

Sodium is essential for the body, but in most populations, including Romania, salt intake is about twice the WHO recommendation of less than 5 g/day, which contributes significantly to hypertension, cardiovascular disease and other non-communicable diseases.

Most dietary sodium comes from processed foods, especially bread, processed meat and cheese, although in some countries, including Romania, salt added during cooking remains an important source.

Salt has sensory, technological and preservative functions, so its reduction must be adapted to each product and must always be accompanied by the re-validation of microbiological safety and shelf life.

Gradual reduction, partial replacement with potassium salts (up to about 30%), flavour enhancers and microstructure-based solutions can reduce the salt content of many foods by 25 - 50% without compromising consumer acceptance.

Significant reductions at population level require an integrated approach that combines food reformulation with clear labelling, consumer education and public policies such as reduction targets and fiscal measures.

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