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Review Article

# Sodium intake and its reduction by food reformulation in the European Union — A review

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ABSTRACT

*Background:* The purpose of this article is to review the current situation with regard to sodium intake in the European Union, provide an update on the efforts being made to reduce the sodium content of food products in various industries via food reformulation and identify the factors motivating food reformulation.
*Methods:* A review was conducted of published literature as well as government and nongovernment organization websites and publications.
*Results:* Food reformulation efforts have been made in the bread, meat, dairy and convenience foods industries. The World Health Organization (WHO) recommendation of <5 g/day of dietary salt intake (<2 g/day sodium) provides an internationally accepted baseline for reformulation efforts. Most Europeans continue to consume salt above the recommended limit. About half of the EU member states have legislated change in the form of taxation, mandatory nutrition labeling and regulated nutrition/health claims.
*Conclusions:* These actions have encouraged sodium reductions in existing food products, but food safety, consumer acceptance, cost and complications arising from the use of sodium alternatives remain limitations to food reformulation.


**Contents**



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## 1. Food reformulation to reduce sodium intake

Salt is the commonly used name for sodium chloride, which consists of 40% sodium and 60% chloride by weight. Salt provides about 90% of the sodium in the human diet [1]. Sodium is essential for the maintenance of cellular membrane potential and the absorption of nutrients in the small intestine. Furthermore, its presence determines the volume of extracellular fluid, thereby maintaining blood volume and blood pressure. However, excessive consumption of sodium has been associated with negative health effects, the most alarming being elevated blood pressure (BP) [2,3]. The prevalence of hypertension (blood pressure ≥ 140/90 mm Hg) exceeds 40% in most European countries [4,5] and is particularly high in eastern European countries such as the Czech Republic, Slovenia, and Hungary (Fig. 1) [6–8] many of which exhibit an extremely high sodium intake [9]. Hypertension is a major risk factor for cardiovascular disease (CVD), the leading cause of death worldwide (Fig. 2) [3,10]. It accounts for 62% of strokes and 49% of coronary heart disease (CHD) [11]. Prospective cohort studies and outcome trials have shown a positive correlation between salt intake and CVD [3, 12]. It was estimated that if the average person would decrease salt intake by about 5 g per day to the intake recommended by the World Health Organization (WHO) a reduction of 23% of strokes and 17% of CVD would result preventing an estimated four million deaths annually worldwide [3]. A meta-analysis by He, Li and MacGregor showed that reduction of salt intake resulted in decreased blood pressure in both hypertensive and normotensive patients. The authors concluded that although a reduction to 5 g salt per day has a positive effect on blood pressure, a further reduction to 3 g salt per day would have a much greater effect [13].

In 2004, the WHO Global Strategy on Diet, Physical Activity and Health was adopted by the World Health Assembly providing an action plan for the control and prevention of non-communicable diseases. In addition to elimination of *trans*-fatty acids (TFA) in foods, a primary goal was the reduction of salt. Due to the success of the Consensus Action on Salt and Health, established in 1996 in the UK, the World Action on Salt and Health (WASH) group was founded in 2005 to achieve salt reductions worldwide by working with governments and the food industry to implement national salt reduction initiatives. Aims of the WASH group include working with food companies to reduce the amount of salt in processed foods and improving consumers' awareness of the impact of added salt [11]. Furthermore, the EU launched the framework for National Salt Initiatives in 2008, aiming for a 16% salt reduction within four years across all food categories to achieve the WHO recommendations of an intake of less than 5 g/day of salt (<2 g/day sodium) for adults [14,15]. Activities to reduce populations' salt intake have included data collection, establishing benchmarks and food categories, increasing public awareness as well as monitoring and evaluation. Promoting food reformulation within the food industry is one of the major challenges of the framework [14].

Food reformulation describes the action of changing the composition of processed foods to obtain a healthier product [16,17]. These changes seek to limit the addition of ingredients such as salt, *trans*-fatty acids (TFA), saturated fatty acids (SFA) and sugar believed to be associated with negative health effects including obesity, diabetes, CHD and stroke when consumed in excess [18–20]. These diseases are the major cause of death worldwide accounting for more than 60% of all deaths [21]. Food reformulation, therefore, is intended to promote health and prevent disease by limiting certain nutrients in the diet. Thus, food reformulation is distinguished from food enrichment and food fortification [16].

### *1.1. Salt intake in Europe*

The salt consumption among adults in most European countries ranges from 7 to 13 g per day according to the European Commission data. Germany, Cyprus, Bulgaria and Latvia reported the lowest salt intake (6.3–7.3 g/day), whereas the Czech Republic, Slovenia, Hungary and Portugal reported the highest salt intake (12.3–13.6 g/day) (Table 1) [14]. Powles et al. reported notably different salt intake levels with the lowest intake values observed in Denmark, The Netherlands and Belgium (8.3–8.8 g/day) and the highest in Hungary, Slovenia, Slovakia, Portugal and Italy (10.7–11.2 g/day) (Table 1) [22]. Thus, both surveys demonstrated that eastern and southern European countries exhibit the highest salt consumption rates. It must be noted that the comparability of the data is limited as three different data collection methods were used to determine salt intake: 24-hour dietary recall, dietary records and 24-hour urine samples. In the study performed by the European Commission in 2013, countries reporting the highest salt intake used the 24-hour urinary sodium excretion assessment method, either alone (Slovenia, Portugal) or in combination with the 24-hour dietary recall (Czech Republic, Hungary), whereas countries reporting the lowest salt intake only used dietary studies for evaluation [14]. Kersting et al. showed that urinary sodium excretion was 1.4–1.7 times higher than the sodium intake estimated by dietary records (3-day food diary) in a previous study. This implies that sodium intake assessed by dietary reports may be underreported by an average of 29%–41% [23]. However, in Hungary, a 24-hour recall resulted in much higher estimated salt intake values (17.2 g/day and 12.0 g/day in men and women, respectively) than the 24-hour urinary sodium estimation (11.2 g/day and 9.2 g/day of salt in men and women, respectively) [14]. Data from different studies are also confounded by the inclusion or exclusion of salt added during cooking or

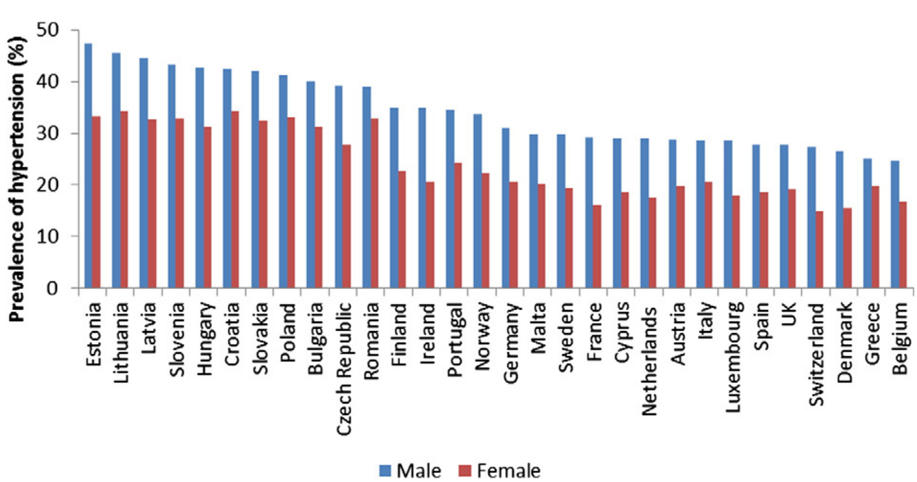


**Fig. 1.** Prevalence of hypertension (≥140/90 mm Hg) among adults aged ≥25 years in the European Union, Norway, and Switzerland [132].

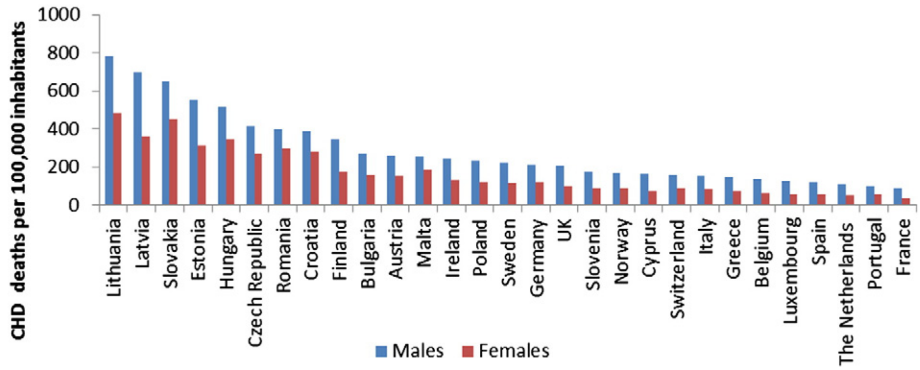


**Fig. 2.** Deaths due to coronary heart disease (CHD) in the European Union (without Denmark), Norway, and Switzerland stratified by sex. Standardized death rate per 100,000 inhabitants [125].

at the table. One limitation of the 24-hour urine assessment is that dietary sources contributing to salt intake cannot be identified. A disadvantage of the 24-hour dietary recall is that the salt content of many foods, including convenience or ready-to-eat foods, is not precisely known [24]. Nevertheless, all studies demonstrate that the salt intake levels across Europe exceed the WHO recommendations. Powles et al. provided a comparison of world salt consumption (Fig. 3). According to their assessment, Europeans consume less salt than Asians, but more than all other peoples [22].

### *1.2. Dietary sources of salt*

In industrial countries, about 75–80% of dietary salt is obtained through processed food consumption, 5–10% is naturally occurring in the foods that make up the diet and the remaining 10–15% comes from salt added during cooking or at the table [15,25]. In contrast, in developing countries, salt used for seasoning plays a much more important role [1]. In China, for example, this accounts for 76% of total salt intake. Soy sauce is also a significant source of sodium in China and Japan [9,26]. Throughout the world, the sodium content of processed foods tends to be many times higher than that of natural foods (Fig. 4). An assessment of processed foods in Australia revealed that sauces and spreads contain the most sodium (1280 mg/100 g) followed by processed meats (850 mg/100 g), snacks (800 mg/100 g), fish products (510 mg/100 g) and bread and bakery products (470 mg/100 g). Food categories low in sodium included cereal and cereal products (210 mg/100 g) and processed fruits and vegetables (210 mg/100 g). The range of sodium content within some categories was extreme, suggesting that it is feasible to produce foods in all categories with lower sodium content [27]. A similar study performed in the United Kingdom detected lower sodium levels in bread and bakery products, meat, and sauces and spreads [28] indicating that the sodium content of processed food varies greatly between different countries and likely between different markets. In 2009, the WASH carried out an international survey revealing great differences in the salt content of products of global brands for purchase in different locations [29]. Variations in salt content may reflect traditional diet habits and taste preferences of the local population and partially explain the wide range of estimated salt intakes around the world. A preferential intake of products containing large amounts of salt may explain why men tend to consume more salt than women, sometimes a third more [14]. Individuals with lower socioeconomic status consume greater amounts of high-sodium processed and packaged foods and adolescents consume significantly more meat and packaged sweets and snacks than recommended suggesting that these populations likely obtain more salt from these sources than other consumer groups [14,30,31].

**Table 1**
Estimated salt intakes (g/day) in Europe according to the EU Salt Reduction Framework and Powles et al. [14,22]. Values are calculated as means. Although comparability of the data is limited both surveys reported high salt intake in Eastern and Southern European countries.

| | EU framework | Powles et al. 2013 |
|---|---|---|
| Czech Republic | 13.6 | 10.1 |
| Slovenia | 12.7 | 10.7 |
| Hungary | 12.5 | 10.7 |
| Portugal | 12.3 | 10.8 |
| Poland | 11.5 | 9.8 |
| Romania | 11.1 | 10.5 |
| Belgium | 10.5 | 8.8 |
| Estonia | 10.0 | 10.0 |
| Norway | 10.0 | 9.7 |
| Spain | 10.0 | 10.2 |
| Italy | 9.6 | 11.2 |
| Lithuania | 9.0 | 10.3 |
| Switzerland | 9.0 | 9.2 |
| The Netherlands | 8.7 | 8.4 |
| Denmark | 8.6 | 8.3 |
| France | 8.6 | 9.6 |
| Austria | 8.5 | 10.0 |
| Finland | 8.1 | 9.8 |
| UK | 8.1 | 9.2 |
| Sweden | 8.0 | 9.3 |
| Slovakia | 7.6 | 10.7 |
| Latvia | 7.3 | 10.6 |
| Bulgaria | 7.1 | 9.2 |
| Cyprus | 6.5 | 10.3 |
| Germany | 6.3 | 9.0 |

In most European countries, a few staple food items are responsible for the highest share of salt intake, i.e. bread, cereals and bakery products are currently the main dietary sources of salt (Fig. 6). Typically, these are followed by meat and meat products, then cheese and dairy products [26,32–37]. The European Nutrition and Health Report showed that the highest consumption of cereals and cereal products as well as meat and meat products occurred in central and eastern Europe [38]. In some eastern European countries (Czech Republic, Poland and Romania), salt used for cooking contributes most to dietary salt intake [14]. In Norway and Spain, meat products play the most important role [14]. Consumption of milk and dairy products, the third major dietary sodium source, was highest in Northern Europe [38]. In Northern Europe, the salt content of bread is relatively low whereas it is relatively high in butter and spreads. Fig. 5 depicts the primary food sources of four European nations as reported in national studies. Despite some regional differences, milk/dairy products, meat/meat products, grain/grain-based products (incl. bread) and vegetables are significant food sources in all these nations (Fig. 5). These four food categories are also reported to be major contributors to salt intake in most European countries (Fig. 6) [14,39].

Information displayed in Fig. 5 provides a comparison of food consumption data collected in a report by the European Food Safety Authority from four different countries judged by the EU to have very

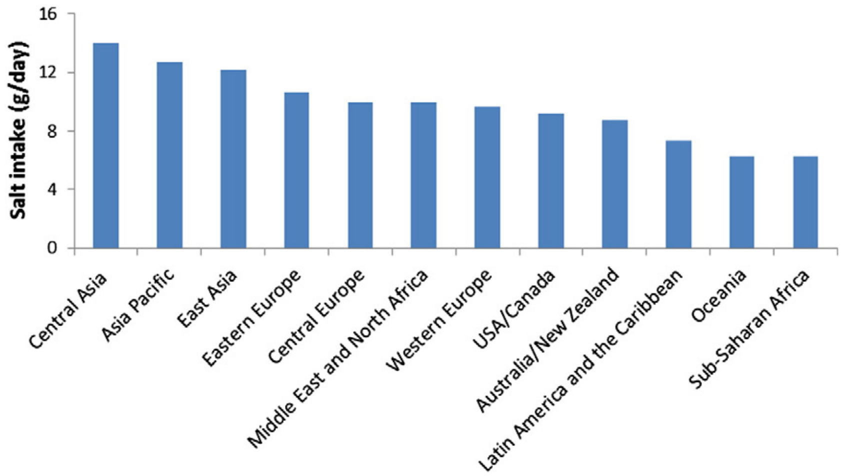


**Fig. 3.** Global salt intakes (g/day) [22].

high (Czech Republic and Hungary) and very low (Germany and Latvia) sodium intake [14,39]. A notable difference is observed in the higher daily intake per capita of meat/meat products, vegetables and grains/grain products in the "high salt" countries in addition to relatively high milk/dairy product intake in relation to the "low salt" countries (Fig. 5). A comparison of data from Hungary in the two figures confirms the important role of these high-salt food groups in the diet (Fig. 5, Fig. 6) [14,39]. Despite broad variations in the dietary habits of adults residing in different European nations (which reflect the regional differences reported by the European Commission), it is evident that reducing salt in the diet of Europeans can be achieved through changes to these basic food categories. The data in Fig. 5 does not distinguish between ready-made meals and individual products. Ready-made meals are thought to contribute to excess salt consumption.

These data verify the importance of cross-sector food reformulation approaches as well as of educating the public about minimizing the addition of salt during food preparation in the home.

## 2. Salt reduction by food reformulation

Since the WHO launched the Global Strategy on Diet, Physical Activity and Health to limit the levels of TFA, SFA, salt and sugar in foods, many companies in the food and beverage industry have reformulated their existing products [25,40,41]. With regard to salt, the UK Food Standards Agency (FSA) started a campaign in 2003 to encourage a voluntary reduction of salt in processed food [42]. A comparison of foods in the United Kingdom in 2006 and 2011 showed an overall mean reduction of the sodium content by 7%, specifically, among convenience foods, dairy products and sauces and spreads, the sodium content

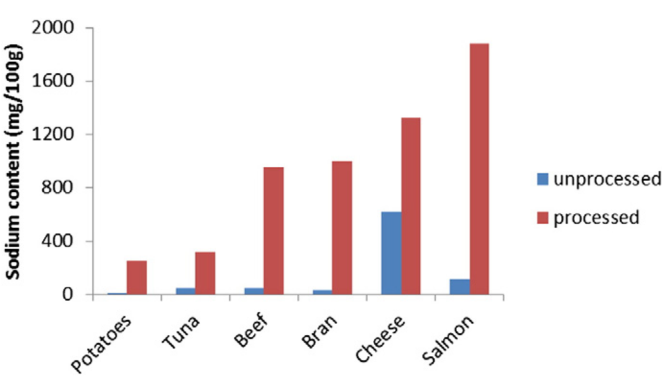


**Fig. 4.** Comparison of the sodium content of some natural (unprocessed) and processed foods [128].

substantially declined. The decreases in these product groups outweighed the increases in the salt content which were observed in some product categories such as non-alcoholic beverages and processed vegetables [43]. Thus, the voluntary salt reduction goals encouraged by the FSA resulted in lower overall salt levels in food available in the UK.

As salt exerts diverse functions in many different types of foods, reformulation must be carried out in a category specific manner (Table 2) [17]. With a growing percentage of the population aware of the potentially adverse consequences associated with excessive salt intake, several companies in the food and beverage industry have already changed their product portfolios to promote healthier diets. For instance, Nestlé removed almost 7,500 tons of sodium from their products since 2005 [44]. Unilever screened more than 16,000 of their products and subsequent food reformulation resulted in a reduction of over 3,000 tons of sodium [25]. The sodium content of Knorr dry soups was reduced by 10%. Kellogg's reported a sodium reduction of 38% in many cereals during the last decade [44]. Salt was reduced by 10–40% in many food categories including bread, breakfast cereals, processed meat, cheese, chips, soups and sauces as well as cakes and biscuits [16]. In this context, it is worth noting that food labels advertising sodium reduction are only permitted when the salt content of the food item is reduced by 30%. However, a reduction of salt by 30% is difficult to achieve in one step and scarcely carried out. The reduction of salt by 30% might also give the consumer the impression that the salt content in the product was much too high prior to reformulation. Consequently, the efficacy of direct advertising salt reduction on food labels is debated. Hence, the global statements made by the large companies listed above are to date the most desired method for promoting food producers' efforts at salt reduction. However, such media power is not available for small and medium enterprises (SMEs), which represent the majority of food producers (e.g. local bakeries). This has been recognized by the European Commission, which has funded different projects for the promotion of food reformulation. For instance, the SALUX project focused on analyzing the situation and extent of food reformulation in the EU, identifying best practices and experiences, and following-up reformulation efforts made in processed food production in the EU [14]. Finally, it aimed to provide a platform (clearing house) and model for the estimation of the overall costs of reformulating a product in SMEs.

Salt provides an inexpensive means to produce long-lasting, tasty food and it plays a critical role in certain aspects of food production. In some cases, a reduction of salt by ~10% can be achieved without other measures (e.g. in the case of bread) [16]. Yet, it was estimated that a sodium reduction of 20–30% increases food cost by 5–30% depending on the type of food [25]. Still, a data analysis indicated that investment of 25.5 million US dollars spent on salt reduction could prevent 6,000 deaths due to CVD leading to savings of 500 million US dollars per

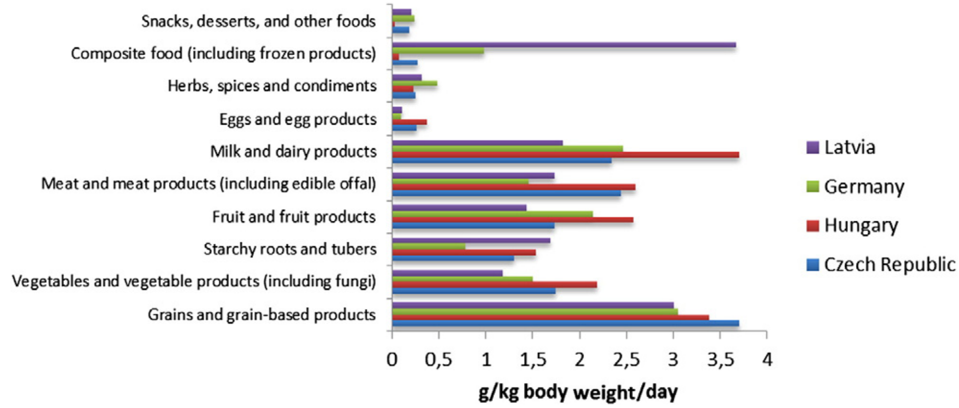


**Fig. 5.** Food consumption in selected European countries [39].

year and demonstrating that the health and economic benefits of salt reduction programs should outweigh the costs of food reformulation [45].

Sodium is the main contributor to food palatability as it increases saltiness and overall flavor by enhancing the taste of other aromatic compounds via cross-modal interactions while suppressing bitterness [25]. Thus, the salt content of a food product is a major determinant of consumer acceptance. Over time, the human salt taste receptors can adapt to low salt concentrations [46,47]; therefore, a small, stepwise reduction of sodium content in processed food cannot be detected [48]. This presents one opportunity for sodium reduction in the food supply; however, an effective change in population intake using a reduction of this type would require cooperation of all market competitors.

If the salt content of a food is reduced, steps must be made to maintain product acceptance such as altering the chemical profile using salt replacers or boosters, maximizing salt receptor stimulation by ensuring quick salt release from the food surface or decreasing the consumer's preference for salt. For example, the addition of specific aroma compounds (e.g. beef flavor, cheese flavor) can compensate for a lack of salt in savory foods and combat the change in flavor profile when salt is reduced [49]. Anchovy and bacon flavors may also be used to increase saltiness taste perception [50]. Finally, altering the structure of a food product, so that the available sodium is more readily released, is an important reformulation alternative.

Currently, different salt reduction strategies exist including small, stepwise reductions to added salt quantities, an increased use of spices and the addition of mineral salts, phosphates and taste enhancers (Table 2) [51]. Because sodium decreases water activity inhibiting the growth of pathogenic and spoilage microorganisms, such as *Listeria monocytogenes* and *Clostridium botulinum*, significant decreases in the salt content must be compensated by the addition of other antimicrobial agents to ensure food safety and preservation [52,53]. Sodium chloride can be replaced up to 30–40% by potassium chloride or by organic acids such as lactates, propionates, sorbates and benzoates without altering the characteristics of the product [54,55]. In meat and meat products, the replacement of NaCl by KCl, $CaCl_2$, $MgCl_2$ or sea salt had no significant effect on the growth of *L. monocytogenes* during storage [56]. In cheese, partial replacement of salt with KCl did not affect the growth of microorganisms such as lactic acid bacteria, yeast and coliforms [57]. Replacing regular salt in white bread with Smart Salt®, a mineral salt mixture containing 40% less sodium chloride, significantly reduced the total aerobic counts after six days of storage [58]. There are also many phytochemicals that exhibit antimicrobial activity including thymol, eugenol, cinnamaldehyde as well as compounds from onion, garlic and mustard. However, these natural plant ingredients are not as effective against microorganisms [52]. A simple sodium reduction without replacement does not necessarily have a negative effect on product shelf life. Reducing the salt content to 2.0% in hotdog sausages, 2.3% in bacon, 1.7% in ham and 6.3% in salami did not affect microbial growth [59].

Potassium chloride is often used as a sodium chloride substitute as it exerts similar antimicrobial effects and technological function. However, a complete replacement is seldom feasible due to its metallic and bitter off-taste [25,60]. An outcome trial demonstrated that the use of a potassium enriched salt which contains 49% sodium chloride,

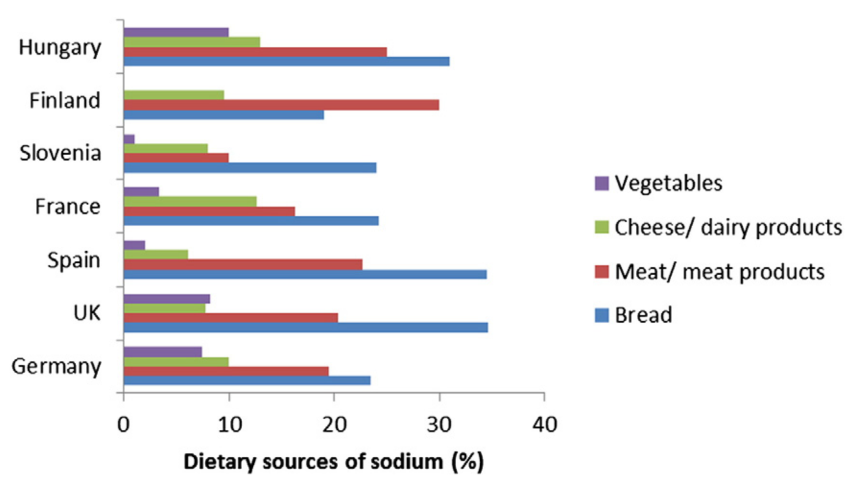


**Fig. 6.** Dietary sources of sodium in selected European countries (%) [26,32–37].

**Table 2**
Strategies for salt reduction in different food categories.

| Food category | Approaches | References |
|---|---|---|
| Bread | Small stepwise reduction of sodium (5% per week until 25%) | [48] |
| | Substitution of sodium chloride by potassium chloride (up to 10%) | [68] |
| | Use of magnesium salt mixtures | [74] |
| | Inhomogeneous distribution of salt increases saltiness perception | [75] |
| | Encapsulated salt enables a reduction of up to 50% | [130] |
| | Use of organic acids such as acetic and lactic acid | [66] |
| | Use of soy sauce | [132] |
| Meat | Replacement of sodium chloride up to 50% by other salts/salt mixtures (potassium chloride, magnesium chloride, potassium lactate, sodium diacetate) | [78,82–84,51] |
| | Substitution of salt by naturally brewed soy sauce | [106] |
| | Use of phosphates to promote water binding capacity of the proteins | [51,78] |
| | Use of flake salt in dry-cured meat products | [78] |
| Cheese | Salt reduction by increasing the moisture content and decreasing the fat content | [92] |
| | Use of potassium chloride | [94] |
| | 1:1 mixture of sodium chloride with potassium chloride | [95] |
| | Use of potassium based emulsifying salts (DPP, TPC) in processed cheese | [91,98] |
| | Saltiness enhancement by specific odors (cheese/sardine aroma) | [127] |
| Soups | General reduction of sodium by almost 50% without affecting consumer acceptance | [105] |
| | Sodium reduction of 17%–33% by the use of naturally brewed soy sauce | [106,129] |
| | Salt reduction of 15% can be compensated by savory aroma compounds (beef/chicken flavor) | [126] |
| | Water-in-oil-in-water emulsions | [64] |
| Ready meals | Reduction of sodium by 30–40% without affecting consumer preference | [100–102] |
| | Use of salt substitutes (e.g. potassium chloride) and flavor enhancers (e.g. yeast extract) | [100–102] |
| | Natural flavor enhancers such as garlic, rosemary, oregano and sage | [103] |
| Snacks | Alteration of crystal size: smaller salt particles induce an increased initial perception of saltiness | [51] |
| | Use of spices | [60] |
| | Replacement of salt by starch in extruded snacks | [108] |

49% potassium chloride and 2% additives resulted in a 17% reduction in urinary sodium-to-creatinine ratio and a 40% decrease in CVD mortality [61]. Magnesium sulphate also provides a salty taste but bitter aftertaste depending on the concentration [51]. Bitter blockers or sweeteners such as sucrose and thaumatin can be used to mask these off-tastes [62].

Salt enhancers provide another opportunity for increasing perceived saltiness of foods. For example, organic acids such as lactates and some amino acids (arginine, aspartate, lysine and glutamate) enhance saltiness [60,63,64]. Furthermore, monosodium glutamate and yeast products can be used to enhance salty taste and are often combined with potassium chloride [51,64]. Little and Brinner showed that citric acid increases saltiness perception in tomato soup [65]. Furthermore, acetic and lactic acid increase salt intensity in breads [66]. Salt structure also plays an important role in salt perception. The smaller the particle size, the higher the salt intensity because the sodium molecule is released faster and the maximum salt intensity is achieved sooner [63].

### 2.1. Bread and cereal products

Bread consumption varies between European countries; it ranges from 100 g/day in the UK to over 400 g/day in Turkey [67]. In the Northern regions, sourdough bread is frequently consumed, whereas in the southern regions wheat bread plays the leading role. There are major differences in the salt content of different types of bread. In France, for example, bread contains 1.8% NaCl, whereas in the UK bread has only 1.0% salt [67]. Thus, the contribution of bread to salt consumption varies greatly depending on location. The most important function of salt in bread is the maintenance/stabilization of the gluten structure. Moreover, salt inhibits the growth of yeast, thereby controlling the fermentation rate [51]. It contributes to flavor and reduces spoilage by controlling water activity in baked products [68]. If salt is reduced to a great extent, the dough is less elastic and becomes sticky [68,69]. Initially, the dough is firmer, but with ongoing mixing, the structure is not stable. However, potassium chloride can also strengthen the gluten structure [70]. Furthermore, salt reduction can result in excessive fermentation, making the dough more acidic and causing excess gas production. Thus, it is important to adapt the proofing time [71]. With increasing yeast activity the amount of free reducing sugars available for Maillard reaction declines. Hence, salt reduction may influence crust color and flavor. The crumb structure is also affected, if sodium is reduced, due to the weaker gluten network and the increased formation of leavening gases [72]. Regarding the effect of salt reduction on flavor, studies reported conflicting results. Girgis et al. demonstrated that a gradual sodium reduction of 5% per week over six weeks (corresponding with a final reduction of 25%) was not noticed by consumers [48]. A 20% reduction of sodium in bread did not affect the taste preference of 60 participants [73]. In contrast, Lynch et al. showed that a salt reduction of 50% altered the bread flavor. Bread without salt was described as yeasty, sour, and acidic [72]. A possible salt alternative for bread is potassium chloride. However, if more than 10% of sodium chloride is replaced by potassium chloride, the flavor of the bread is negatively influenced as potassium has a metallic and bitter aftertaste [68]. Another possibility is the use of magnesium salts. Charlton et al. successfully substituted over 30% of sodium chloride with a mixture of magnesium chloride, potassium chloride and magnesium sulphate [74]. Noort et al. showed that an inhomogenous distribution of salt in bread enables a reduction of the salt content while maintaining saltiness [75]. In cakes, sodium chloride plays a minor technological role and is primarily added to improve flavor. More important is the use of sodium carbonate and sodium bicarbonate for leavening [52]. Whey permeate, which is rich in minerals, was used to produce low sodium bakery products [76].

Studies analyzed the implementation of bread reformulation over the past years revealing that much effort has been made to reduce sodium in breads. The salt content of bread in the UK decreased by about 20% from 2001 to 2011 (from 1.23 to 0.98 g/100 g). By 2011, 71% of all breads met the FSA targets of ≤1 g/100 g, whereas in 2001 only 25% of all breads met the targets [77]. In terms of feasibility and marketability, it seems that salt reduction can be achieved in most bakery products.

### 2.2. Meats and meat products

Sodium occurs naturally in meat up to a concentration of 60–80 mg/100 g, which is equivalent to 0.15–0.2 g salt/100 g. In processed meat and meat products, the sodium content is much higher with highest levels observed in cured meat products and sausages [78]. Salt increases the hydration and water binding capacity of proteins and improves the texture and viscosity of meat products. Saltiness is increased in products with a high fat content and reduced in products with high protein content. Therefore, it is easier to reduce the salt content of high fat meat products [79–81]. As salt reduces water activity in meat and meat products, it ensures preservation and microbial safety. Consequently, salt reduction is equivalent to shelf life reduction. Sodium chloride reduction can be compensated by the addition of other salts with antimicrobial activity such as potassium chloride, magnesium chloride, potassium lactate or sodium diacetate [51,78,82]. Sodium is also important for texture as it binds and solubilizes myofibrillar proteins, thereby promoting tenderness and juiciness of meat products. If salt is removed, the water holding capacity of the proteins is reduced resulting in increased cook loss [80]. Furthermore, it contributes to the characteristic taste of meat as it enhances savory and other typical meat flavors [51, 78]. Potassium chloride is the most common salt substitute used in meat products and has been used up to a ratio of 50:50 sodium chloride/potassium chloride without eliciting negative sensory characteristics [78]. A mixture of potassium chloride, magnesium chloride and calcium chloride may replace 40–50% of sodium chloride in dry-cured pork loin without negatively affecting sensory and safety characteristics [83]. An overview of salt mixture applications in meat product preparations was previously published by Weiss et al. [84]. Sodium can be partially replaced by calcium ascorbate or magnesium chloride improving the nutritive value of the product [85,86]. However, the use of these salt replacers is limited due to the inferior technological characteristics compared to sodium chloride [86]. Commercial mineral salt mixtures such as Pansalt can be used as salt replacers. In this formulation, almost 50% of the sodium chloride is replaced by potassium chloride, magnesium sulfate and the hydrochloride of the essential amino acid L-lysine [78,87]. To improve the taste of such salt mixtures bitter blockers such as adenosine monophosphate (AMP) can be used. Other masking agents are spices and herbs such as pepper, onion, garlic and chili [86]. Phosphates can be used to reduce salt content as they promote protein extraction and increase water holding capacity in meat products. If sodium phosphate is used, the amount of sodium chloride can be reduced resulting in a net sodium reduction [51,78]. Flavor enhancers such as monosodium glutamate, magnesium glutamate, yeast extracts or naringin were successfully added to meat products, thereby increasing the perceived saltiness and palatability [79,88]. The physical structure of salt also plays a role in saltiness perception. Flake salt dissolves more rapidly than granular salt and is more suitable for products in which no water is added during processing such as dry-cured meat products [78]. Studies of processing techniques showed that there is potential for increasing protein extraction and water binding capacity of low sodium products by high pressure technology and the use of pre-rigor meat [89,90].

### 2.3. Cheese and other dairy products

In cheese, salt creates flavors during ripening by controlling the activity of starter cultures, secondary organisms and enzymes. It promotes syneresis, so it determines moisture and texture of the cheese. Proteolysis is strongly regulated by salt content and is a prerequisite for flavor and body development. Furthermore, the amount of salt correlates with sugar fermentation, thereby controlling the acidity of the cheese. Additionally, the water binding capacity of salt ensures food safety and shelf life of the cheese [51,91]. Low-fat cheese has a higher moisture content meaning the salt to fluid ratio is lower than in normal cheese with the same total salt content. This promotes the growth of spoilage organisms reducing shelf life and limiting the extent of sodium reduction in low-fat cheese [91]. Phan et al. reported that saltiness perception strongly depends upon the fat content of the cheese. The higher water/fat ratio of a soft cheese increases sodium release and saltiness perception compared to a hard cheese with a low water/fat ratio. They concluded that a salt reduction in cheese is possible by increasing the moisture content and decreasing the fat content [92]. However, in low-fat products salt removal diminishes aromaticity and flavor intensity. So, producing low-fat, low-sodium cheese is a challenge for the industry [93]. Saltiness is one of the most important cheese characteristics for consumers. A reduction of about 25% from 1.8% to 1.4% salt is noticed [91]. Metzger and Kapoor developed a fat-reduced and sodium-reduced cheddar cheese (12.3% fat, 97 mg sodium and 245 mg potassium in 100 g cheese) that exerted the same sensory and textural characteristics as traditional cheeses [94]. The use of salt substitutes provides an opportunity to reduce sodium without losing desirable properties. Exclusive use of potassium chloride, magnesium chloride or calcium chloride (1.5%) as well as a 1:1 ratio of sodium chloride with magnesium chloride or calcium chloride resulted in unacceptable cheese [95,96]. Only a mixture of sodium chloride and potassium chloride (1:1) achieved acceptable results in the tested products [95]. In processed cheese, emulsifying salts enable the emulsification of casein proteins by disrupting the calcium-phosphate network [91]. Potassium-based emulsifying salts such as dipotassium phosphate (DPP) and tripotassium citrate (TPC) can replace disodium phosphate (DSP) and trisodium citrate (TSC), thereby producing low-sodium cheese. However, the substitution often causes a loss of firmness of the processed cheese as TSC has a higher meltability than TPC. Furthermore, the use of DPP instead of DSP has an impact on flavor due to potassium's metallic note [97]. Henson successfully substituted DSP with DPP and tricalcium phosphate (TCP) in processed cheese obtaining a product with about 50% less sodium [98]. It appears that salt reduction in cheese is more challenging than in bread and most meat products. According to Mintel's Global New Products Database (GNPD), there were no reduced or low-sodium processed cheeses on the global market in 2008 [91].

### 2.4. Other foods

The UK FSA 2017 Salt Reduction Targets encompass recommended sodium limits for numerous other food categories including ready meals, soups, packaged sauces, crisps and snacks, baked desserts and canned vegetables among other products [99]. Since 2005, these targets, developed together with industry representatives, non-governmental organizations (NGOs) and consumers, have provided a baseline for sodium reductions and have been frequently updated to reflect recognition and use by the food industry and more restrictive recommendations from the health sector. Thus far, the FSA reports that the salt content of available foods has been reduced by >11 million kg and many industries are voluntarily meeting the targets [99].

An Irish study came to the conclusion that a chili con carne ready-meal containing a nucleotide yeast extract was comparable to a 1% salt formulation. Salt substitutes were used in the same meal to achieve a >50% sodium reduction, and up to 40% of the salt in the original formulation could be removed without consumers tasting a difference [100]. Follow-up studies with a chicken curry meal and a lasagna meal resulted in salt reductions of 30% without diminishing consumer acceptance [101,102]. They also identified garlic, rosemary, oregano, and sage as effective flavor enhancers of ready-meals suitable for use when sodium is restricted [103]. More recently, a study conducted by researchers at the University of Vienna determined the salt content of ready-made meals on the European continent to generally be >1.8 g/100 g. Pizza and pasta dishes contained the highest salt content of products evaluated. However, the salt content varied significantly, even between foods with a similar name and within the same product category. The researchers also tested a stepwise reduction of salt in numerous convenience meals and verified it as a method for maintaining quality and consumer acceptance [104].

Likewise, it was found that the salt content of traditional vegetable soups could generally be reduced by 48% without impacting consumer acceptance [105]. Sauces and soups often contain thickeners to achieve desired consistency. The use of thickeners results in decreased saltiness and total flavor perception [51]. This phenomenon is generally observed as saltiness perception declines with increasing viscosity in all product categories [25,60]. Soy sauce has been recommended as a salt enhancer for low-sodium soups and salad dressings that has no effect on consumer acceptance [106]. Also, water-in-oil-in-water emulsions can be used in sauces and other liquid food products to decrease the salt content. In these double emulsions, less salt is needed to achieve the saltiness of single emulsions [107].

In extruded snacks, salt controls expansion of the dough. In this context, salt can be partially replaced by starch with high amylopectin content, which also contributes to adequate expansion of the dough [108] and flavor can be enhanced by the increased use of spices [60].

Fermented vegetables, while not contributing significantly to total sodium intake in population studies, are traditionally preserved with a high sodium solution. Efforts to limit the sodium content of these products are underway, but further research is needed [109].

## 3. Legislative approaches

Identifying the most effective motivators of food reformulation activities is important for determining recommendations for national intervention strategies. In the WHO European region, about half of the 53 member states have policies addressing salt reduction [15]. Strategies adopted to date by these nations include increased taxation of foods high in sodium, mandatory labeling of sodium content, and regulation of nutrition-related health claims [110,111]. An obligatory food reformulation program has demonstrated more success in practice and in models of potential intervention outcomes indicating that legislation is likely to be more effective than a voluntary approach [112–114].

### *3.1. Taxes*

Taxation of foods identified as “unhealthy” is controversially discussed. While the food industry does not endorse the separation of foods that promote or threaten health, the WHO supports increased regulation of food quality [67]. It has been shown that food consumption is correlated with food prices and has a direct influence on health parameters [115]. Nevertheless, a reduction of the salt content in foods by the food industry results in a greater reduction in sodium intake than taxation of high sodium foods. Portugal and Hungary are currently the only countries with taxes on foods with a high salt content [116]. In Hungary, a tax for salty snacks with a salt content of >1 g/100 g and for condiments exceeding 5 g salt/100 g was established in 2011 [14]. For both product categories the tax is 0.8 €/kg salt. An assessment of the impact of the health product tax reported declines in sales and consumption of salty snacks by 26%. The price increase was reported to be the main reason for the change in consumer behavior, followed by increased awareness of salt's negative health effects. Due to the tax, the salt content of many foods has been decreased, some by up to 85% [33].

### *3.2. Nutrition and Health claims*

In 2006, the European Parliament and the Council launched the Regulation EC No 1924/2006 on nutrition and health claims made on foods. In 2012, the European Commission published the register on nutrition and health claims establishing a list of permitted claims and limiting the number of permitted claims for food items. Four nutrition claims refer to salt/sodium content (Table 3) [110]. There is one authorized health claim for foods with low or reduced sodium: “Reducing consumption of sodium contributes to the maintenance of normal blood pressure” [111]. (See Tables 1 and 2.)

### *3.3. Nutrition labeling*

Presently, there is no international standard for sodium versus salt labeling. Whereas sodium is listed on nutrition labels in the USA, the term salt is more common in the EU [117]. Altering labels to display sodium content may result in consumer confusion, as many are not aware that the salt content is 2.54 times higher than the sodium content when the source is sodium chloride. Research exploring public understanding of sodium and salt labeling found better awareness and understanding of salt throughout the population and great confusion regarding the relationship between salt and sodium. Some participants regarded sodium as another name for salt. Others considered it a component of salt, but were not certain whether it is nutritionally beneficial or harmful [118]. The Regulation (EU) No 1169/2011 on the provision of food information to consumers, adopted by the European Parliament and the Council in 2011, counteracts this problem. According to the regulation, the term salt instead of sodium must be used on food labels to ensure consumer understanding [119]. Within the WHO European Union, 17 member states have already implemented nutrition labeling on food packaging [15]. In Finland, a warning label must be applied to products with high salt content. Additionally, a low salt label exists for various food categories (Table 4). Both labels are intended to help the consumer choose healthier products [120]. Since the implementation of this policy in the early 1990s, salt content of studied foods in Finland has decreased by about 20–25%. Moreover, a Finish survey reported a 40% decrease in dietary salt consumption over the last 30 years [121]. In the United Kingdom, there are two types of nutrition labeling. Firstly, there is a voluntary label consisting of a traffic light signpost system which uses an assessment of the saturated fat, sugar and salt content to indicate the rate at which the product should be consumed as well as the quantity of these nutrients. Thus, red (high) indicates that a product should be consumed with caution, yellow (medium) indicates that a product should be consumed with awareness of increased risk of health effects and green (low) indicates that these nutrients should not contribute to any health risk via this product, if standard serving sizes are consumed. The second variation of front-of-package labeling used in the UK is the guideline daily amount (GDA) system which provides information about the total amount of calories, fat, saturated fat, sugar and salt in the product as well as the percentage of an adult's guideline daily amount met by one serving [15]. A review of front of package labels used around the world determined that the multiple traffic light label has the most empirical support and is most effectively used by consumers. If such labels are supported by non-industry (i.e. government, NGO) bodies, they will likely be recognized as conveying legitimate information and consumer pressure for improvements in food product formulations is more likely to result [122].

Although legislation requiring food labeling can help in promoting consumer awareness and aid consumer identification of healthier products, it should be noted that food reformulation across all product categories is more effective toward reducing populations' salt intake [51]. For some products, legislation actually limits the opportunity for reformulation. These so-called protected designation of origin (PDO) products such as Parmesan, Prosciutto di Parma, Feta, and Camembert de Normandie must be manufactured (prepared, processed and produced) according to traditional methods. Therefore, the options for altering the salt content of these products are limited [51].

### *3.4. Other*

Other nutrition related policy interventions used in Europe have been summarized by Traill et al. and include advertising controls, public health information campaigns, nutrition education, menu labeling, and

**Table 3**
Nutrition claims referring to sodium/salt content [110].

| Nutrition claim | Sodium content (per 100 g or 100 ml) | Equivalent salt content (per 100 g or 100 ml) |
|---|---|---|
| Low sodium/salt | 0.12 g | 0.30 g |
| Very low sodium/salt | 0.04 g | 0.10 g |
| Sodium-free/salt-free | 0.005 g | 0.01 g |
| No added sodium/salt | 0.12 g | 0.30 g |

**Table 4**
Salt labeling in Finland [133]. There is a low-salt label for products with a low salt content and a high-salt label for products with a high salt content.

| Food category | Low-salt limit | High-salt limit |
|---|---|---|
| Bread | 0.7% | 1.3% |
| Sausages | 1.2% | 1.8% |
| Cheese | 0.7% | 1.4% |
| Butter/margarines | 1.0% | 2.0% |
| Rye crisp bread | 1.2% | 1.7% |
| Breakfast cereals | 1.0% | 1.7% |
| Processed meat | 1.2% | – |
| Processed fish | 1.0% | – |
| Soups/sauces | 0.5% | – |

regulation of workplace or school cafeteria meals [123]. To date, these interventions have not been widely implemented and are not thought to have made any impact on sodium reduction by encouraging food reformulation.

## 4. Conclusion

Since the EU framework on National Salt Initiatives was established in 2008, sodium consumption in the European Union has decreased in some countries (UK, Finland, France and Lithuania), though others have not observed declines (The Netherlands, Slovak Republic, Sweden and Switzerland). A summary of the current situation is provided in Table 5. The recommended intake level of less than 5 g salt/day as well as the goal of 16% sodium reduction within four years has not yet been achieved. There are many reasons for the slow progression toward these goals. These include the setting of national benchmarks according to the baseline sodium contents of foods in those markets rather than major pushes to reach an international standard, a broad range of salt content in food categories, as well as unique dietary patterns across Europe that prevent direct transfer of successful salt reduction efforts to other markets. The involvement of food industry specialists and consumers in salt reduction and targeting food categories from which most inhabitants obtain their salt is vital to ensuring the long-term integration of reduced sodium foods into the diet. Increasing consumer awareness of salt remains important, particularly when reformulation by the industry is voluntary. Front-of-package sodium content labeling is useful for informing the consumer, but only positively impacts human health when the consumer is informed and motivated to choose the healthiest products. This is particularly true if removing salt from product formulations results in higher sales prices. Despite the fact that numerous leaders in the food industry serve populations across Europe, no single database provides nutritional information, specifically sodium content, for foods sold in Europe. The lack of information on baseline sodium content of European food products limits the ability to evaluate the contribution of food reformulation to reductions in dietary sodium intake. The involvement of European nations in an international food observation system such as The Food Monitoring Group's global branded food composition database would enable better analysis of food reformulation activities in the future [124].

Slight to moderate salt reductions in bread as well as in ready-meals, soups, sauces and snacks offer the greatest chances for change in the near future. Further research on the effective methods for reducing sodium content through changes to food products and processing methods is necessary in order to address the challenges of safe and competitive food production in many sectors. It is evident that food reformulation will continue to contribute to reductions in dietary sodium intake as long as local and international coalitions remain involved in the push for healthier foods and consumer demand for these products continues to grow.

**Table 5**
Summary of key points regarding food reformulation.

- Contributed to decreases in sodium intake, but further decreases needed.
- Salt reduction in bread, ready-meals, soups, sauces and snacks is feasible and effective.
- Salt content within similar food products is broad indicating easy opportunity for change.
- Slowed by lack of international sodium recommendations and standardized labeling
- Success depends on the involvement of food industry specialists and consumers in reformulation.
- Research is needed on greatest dietary salt sources, salt content of certain foods, and the most effective methods for reducing salt consumption by reformulation in EU countries.
- A database of food product nutritional information for EU markets would be useful.

## Conflict of interest

None.

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