Understanding Sodium Replacements from a Food Safety and Health Risk Perspective

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Contents

Introduction

Excess dietary sodium has been reported to adversely affect health by increasing blood pressure and appears to have other negative health effects as well. (63) According to data from NHANES (2005-2006), over 95% of men and over 75% of women in the US now exceed the recommended daily tolerable upper intake of sodium (2.3 g/d, equivalent to 5.8 g NaCl, table salt*) that was established by the Institute of Medicine (73) and recommended in the 2010 Dietary Guidelines for Americans (121). For persons who are 51 and older and those of any age who are African American or have hypertension, diabetes, or chronic kidney disease, the recommended maximum daily intake is 1.5 g sodium. (147) Because these at-risk groups comprise 50-70% of the adult population and a majority of people develop hypertension as they age, the American Heart Association recommends that 1.5 g sodium/day should be the target intake for the general population. (8)

Consequently, state and national governments and the World Health Organization are considering strategies to reduce overall population sodium intakes as part of a program to reduce hypertension and cardiovascular disease, improve public health, and reduce healthcare costs. (51;62;152) It has been estimated that about 80 – 85% of the sodium consumed in Europe, Australia, and North America is salt that has been added to processed and restaurant foods. Although foods such as sauces, gravies, spreads and processed meats often have the highest concentrations of sodium, breads, grains and cereals are usually major contributors to dietary sodium intake because they are eaten in greater quantities. In Japan and China, soy sauce, salt added during cooking and salted fish and vegetables are primary sources of dietary sodium. (6;113;153) Therefore, in Western countries food processors are being pressured to reduce sodium levels in their products. An international organization of experts from 81 countries, WASH (World Action on Salt and Health), is consulting with food companies and governments to plan effective programs for reducing salt intakes. (http://www.worldactiononsalt.com/)

Since sodium affects the taste, texture, and safety of foods, the consequences of reducing sodium levels in various foods must be evaluated carefully. (32;37;40;85) This report will briefly review health concerns associated with high intakes of sodium and important functions of salt in foods. Other food components that may substitute for some of the functions of salt in foods will be discussed with respect to potential safety considerations.

* 100 mmol sodium = 2.3 g sodium = 5.8 g table salt

Adverse Health Effects of High Dietary Sodium intake

General

Sodium is an essential nutrient, the cation mainly responsible for regulating extracellular fluid volume and plasma volume. It also determines membrane potential of cells and participates in the active transport of some molecules across cell membranes. Other cations, including potassium and calcium, interact with sodium and influence its physiological effects. (1)

Humans can survive on diets with a wide range of sodium concentrations as demonstrated by the 1985-1987 INTERSALT study of blood pressure and electrolyte excretion in 32 countries, including remote unindustrialized populations as well as major Asian, European, and North American nations. Lowest salt intakes were recorded among the Yanomamo Indians in Brazil and highest intakes occurred in residents of Tianjin, China. In European and North

American countries, median daily sodium intakes ranged from 2.3 g to 4.3 g (75). A recent review of more than 100 publications documenting sodium intake in adults and children in countries around the world also reported that adults in most countries consume > 2.3g sodium/d, greatly exceeding physiological needs of <0.6 g sodium per day* (16).

Approximately 98% of dietary sodium is absorbed in the intestine and excess sodium is excreted mainly by the kidneys. In healthy adult humans at steady state conditions, urinary sodium excretion roughly equals intake. Several hormones and the sympathetic nervous system enable healthy humans to adapt to different dietary salt levels and maintain plasma levels of sodium within an optimal range by altering the excretion of sodium in sweat and urine in response to changes in dietary sodium intake. However, as people age or develop certain chronic diseases, kidney function declines thereby diminishing the efficient excretion of excess sodium. This can lead to an increase in plasma volume and may stress the cardiovascular system by inducing hypertension. Hypertension, in turn, is correlated with higher risk for coronary heart disease, stroke, and end-stage renal disease. (61;63)

Hypertension

Hypertension is a recognized risk factor for CVD and is often associated with other cardiovascular risk factors. Approximately two-thirds of adults in the U.S. have either hypertension, defined as untreated systolic blood pressure (SBP) >139 mm or diastolic blood pressure (DBP) >89 mm, or pre-hypertension with SBP 120 to 139 mm or DBP 80 to 89 mm. Untreated hypertension is associated with increased incidences of diabetes, heart disease, stroke, and kidney disease. Therefore, there is universal agreement that interventions that reduce or prevent development of high blood pressure would significantly improve health (35). Age, body mass index, activity levels, and dietary sodium and potassium are all known to affect blood pressure. Some analysts question the importance of dietary sodium, relative to other factors, as a cause of hypertension in the general population (68).

Evidence supporting the connection between sodium intake and blood pressure includes: (1) epidemiological studies including surveys of populations with different sodium intakes, (2) studies of large populations which have achieved significant average reductions in salt intake, (3) clinical studies in which people consume diets with high or low sodium levels, and (4) experimental studies with animals including chimpanzees and salt-sensitive rats. Other studies have investigated physiological effects of sodium in the body to understand how it impacts blood pressure.

Data from numerous epidemiological studies indicate that higher intakes of salt or sodium are associated with elevated blood pressure in populations overall. The INTERSALT study found that 4 groups of people, living in nonindustrialized areas with very low sodium intakes, had low blood pressure readings that did not increase with age. Data from another 45 populations in more industrialized areas indicated that higher urinary sodium excretion was significantly correlated with blood pressure and age-related increases in blood pressure. A negative association was observed between potassium excretion and blood pressure at most centers (75). The INTERMAP study of blood pressure and urinary sodium levels in over 4600 adults in the US, UK, Japan, and China revealed that several dietary variables, including sodium, were correlated with blood pressure measurements (16).

Finland initiated major efforts to reduce cardiovascular disease and promote health, following publication of data in the late 1960s showing that Finnish men had a very high rate of coronary heart disease mortality. Public information campaigns and collaborations with the food

industry to develop lower-salt foods were instituted. Dietary salt intake among Finnish men declined from 12.0 to 13.2 g/d in 1979 to 8.6 to 9.5 g/d in 2002. During this time, mean SBP in males declined by an average of 8 mm despite an increase in mean body mass index (92). Other population intervention programs involving thousands of people in Japan, China, and Portugal also demonstrated decreases in average population blood pressure in response to a reduction in dietary sodium (61).

Inconsistent changes in blood pressure have been reported from short term studies (1 week or less) employing high- and low-salt meals or diets. These results have been cited by those who are skeptical of programs to reduce dietary sodium (Taubes 1998). However, these trials may not reliably predict results of currently-recommended, long-term, modest decreases in dietary sodium.

Many longer term studies documented reductions in blood pressure in persons consuming low sodium diets. A randomized double-blind crossover trial of a modest reduction of salt (from 9.7 to 6.5 g salt/day) demonstrated that the lower sodium diet was associated with significant reductions in blood pressure in white, black, and Asian subjects with mildly raised blood pressure in the U.K. (65). A recent, randomized crossover trial of low and high sodium diets (50 and 250 mmol/day for 7 days each) reported significant reductions of SBP and DBP of 22.7 and 9.1 mm Hg in patients with resistant hypertension (blood pressure that remains elevated despite the use of 3 antihypertensive medications) (123). A meta-analysis of 28 dietary interventions that lasted for at least 1 month demonstrated that reductions in dietary sodium significantly decreased blood pressure in both normotensive and hypertensive individuals. (87)

Some individuals appear to be "salt-sensitive" and experience a significant drop (at least 10%) in blood pressure when consuming a low-salt diet, while others are “salt-resistant.” A high prevalence of salt sensitivity occurs among persons with hypertension, diabetes, chronic kidney disease, and metabolic syndrome as well as among persons over 40 and African-Americans (23;61). USDA estimates that these at-risk individuals constitute nearly 70% of the adult population in the U.S. (51). Gender differences have also been reported with females exhibiting greater salt sensitivity (66).

Salt sensitivity appears to be caused by impaired kidney function - either a decrease in ultrafiltration of sodium from blood or an increased renal tubular reabsorption of sodium into blood. Chronic kidney disease, genetics, changes in physiology during aging, obesity, diabetes, and some dietary and life style variables can all affect kidney function. This condition also appears to be a risk factor for cardiovascular disease independent of its effects on blood pressure. (87;154) Data from some studies on salt sensitivity indicate that 67% of hypertensive people are moderately to strongly salt sensitive while 42% of normotensive people have some degree of salt sensitivity. A reduction of sodium intake would likely benefit all these people. (83;130)

Experimental studies with several species of animals documented increases in blood pressure with higher salt intakes (61). Chimpanzees fed diets with high levels of potassium and high or low levels of sodium had significantly lower SBP and DBP on the lower sodium diets (42). A review of long-term experiments on salt and hypertension in animals noted that salt has 2 distinct effects: (1) a rapid rise in blood pressure in response to increased salt occurring over days or weeks and (2) a slow, progressive increase in blood pressure during a significant portion of the lifetime of normal individuals. In some species this long-term increase in blood pressure appeared irreversible and may correspond to the age-related increase in blood pressure observed in human populations (148).

Other dietary constituents, including potassium, magnesium, and calcium, affect blood pressure. The DASH (Dietary Approaches to Stop Hypertension) diet, which provides a significant amount of these minerals from fruits, vegetables, and low-fat dairy products, has been shown to reduce blood pressure (1;59;73). In a study comparing consumption of control "typical American" diets and DASH diets containing several sodium levels (1.15 to 3.44 g sodium/d), average SBP was significantly lower on the DASH diet compared to the control diet at all salt levels. SBP also decreased significantly with a decrease in dietary sodium on both the "typical" diet and the DASH diet . The combination of the DASH diet and reduced dietary sodium appeared to have an additive effect in reducing SBP. Greater mean reductions in blood pressure were observed in persons with hypertension and in African-Americans than in other subgroups (128). The DASH diet was also shown to enhance the effects of hypertensive medications in reducing blood pressure. (71)

In a attempt to identify the important components of the DASH diet, blood pressure in obese hypertensives was compared during consumption of their usual diet, a DASH diet, and usual diet with potassium, magnesium, and fiber added to match levels in the DASH diet. Although the supplemented diet reduced blood pressure, the DASH diet did this more effectively indicating that multiple nutritional factors, beyond those tested, are important. (2) Some evidence suggests that dietary nitrate, present in vegetables, may have a favorable effect on blood pressure by generating nitric oxide (NO) to reduce oxidative stress markers. (21)

Mechanisms by which sodium affects blood pressure and the circulatory system are not completely understood. It has been suggested that, in response to high salt intake, persons with salt-sensitive hypertension do not excrete as much sodium in urine as salt-resistant individuals. Higher serum sodium levels would be followed by an expansion of plasma volume, an increase in cardiac output, and a sustained increase in systemic vascular resistance. This may occur in some people. However, a trial with healthy Black adults demonstrated that salt-loading induced similar serum sodium concentrations and similar increases in plasma volume and cardiac output in salt-sensitive and salt-resistant individuals. However, blood vessels of salt-resistant persons dilated in response to high salt intake and thereby prevented a significant increase in blood pressure did not increase significantly. This vasodilation did not occur in the salt-sensitive subjects (132).

Cardiovascular disease (CVD)

Correlations between sodium intake and cardiovascular disease and mortality are difficult to establish because this disease develops over many years and is affected by several dietary variables and lifestyle characteristics. Some review papers have generally concluded that the overall epidemiological evidence for a positive correlation between sodium intake and CVD is not strong (3;4;150). Results from recently published studies illustrate the conflicting results from studies with different populations. (29;30;50;99) (48)A recent meta-analysis of 13 prospective studies investigating the relationship between dietary salt and development of cardiovascular disease and stroke concluded that data indicated that a high intake of salt was associated with a greater risk of these diseases. The associations were stronger in studies with a longer follow-up period and in those which included subjects with a wider range of sodium intake.(139) Using the Coronary Heart Disease Policy Model, a computer simulation of heart disease and stroke in U.S. adults, the costs and effects of different interventions to reduce incidence of these diseases was estimated. Reducing dietary salt by 3 g/d was projected to reduce annual number of heart attacks by 54,000 to 99,000 and to reduce strokes by 32,000 to 66,000

annually. Reduction in dietary salt was more cost-effective than medications to reduce blood pressure. (14)

Some characteristics of vascular function, associated with risk for cardiovascular disease, are easily measured and compared to salt intake. Higher dietary sodium levels have been reported to significantly increase pulse wave velocity (a measure of arterial stiffness) (65;145) A systematic review of 38 clinical trials to assess effects of dietary nutrients on arterial stiffness reported that there was limited but consistent evidence that salt restriction reduced arterial stiffness. (119)

Dietary salt has also been reported to increase overproduction of reactive oxygen species (7) and impair relaxation that should occur in smooth muscles in the endothelium of arteries, in response to shear stress of flowing blood. Consumption of a diet containing 1.15 g sodium/d) improved flow-mediated dilation in arteries in a group of overweight/obese individuals as compared to that observed in persons consuming diets containing 3.46 g sodium/d. (35). Potassium chloride and potassium bicarbonate also significantly improved flow mediated dilation. (64)

Bone disease

Metabolism and intercellular transport of sodium and calcium are linked and, therefore, high-salt diets may affect calcium retention and bone density. Normally the body absorbs about 27% of dietary calcium from the intestines but this can change in response to suboptimal or excess serum calcium levels and the presence of vitamin D and other nutrients. Data from several studies have demonstrated that a higher sodium intake is correlated with greater urinary losses of calcium. (20;47;96) Age, gender, menopausal status, and other dietary constituents are known to also affect the excretion of calcium in urine.

Bone mineral density and bone turnover are impacted by calcium intake and excretion. Calcium loss in urine is not necessarily directly related to bone health. Persons consuming the currently recommended amounts of calcium (1200 mg/d for women > 50years; 1000 mg/d for men and for women <50) may be able to increase intestinal absorption to compensate for the increased calciuria that is caused by an intake of an additional 2.3 g sodium/d. However, a calcium intake of 600 mg/d or less will most likely not provide enough calcium to compensate for increased calcium excretion (67). A recent study with post-menopausal women found that bone calcium balance was negative on low-calcium diets (518 mg/d) regardless of sodium intake. On moderate calcium diets (1284 g/d), bone calcium balance was positive when sodium levels were low (1.54 g/d), but not when they were high (4.42 g/d) (144).

Other dietary constituents affect sodium and calcium metabolism. The DASH diet, rich in fruits and vegetables, is associated with significantly reduced markers of bone turnover in adults as compared to the typical American diet (96) DASH diet contains approximately three times the amount of calcium, magnesium, and potassium and more compounds that generate basic ions like bicarbonate during metabolism than a "typical" American diet.(137) DASH

Typical American diets produce a low-grade metabolic acidosis (average of +48 mEq/d), while diets of preagricultural humans were net base-producing (average of –88 mEq/d). Cereal grains, the most commonly consumed foods in modern diets, yield net acid when metabolized (137). An elevated intake of sodium chloride has also been shown in human clinical studies to result in low-grade metabolic acidosis (45;47). Low-grade metabolic acidosis, caused by diets deficient in fruits and vegetables and containing excess sodium chloride, may negatively impact bone health by increasing bone resorption and calcium excretion (106;158).

Other reported health effects of salt

Epidemiological data from the Health Professionals Follow-up and the Nurses' Health studies found that persons following a DASH-style diet (including low dietary sodium) had a markedly decreased risk for kidney stones. (143) High urinary sodium concentrations are correlated with high urinary calcium levels and increased calcium excretion in persons on high-salt diets may contribute to formation of calcium oxalate stones. (116) One study of stone formers following a low sodium diet for three months found that their urine contained lower levels of sodium, calcium, and oxalate than at baseline. (114) However in one other study, urinary sodium and calcium concentrations were positively correlated in stone formers but urinary sodium and urine calcium oxalate supersaturation were negatively related. (41).

Some research suggests that high dietary sodium levels are associated with other health issues including gastric cancer, kidney disease, and severity of asthma. Data supporting these connections are not as extensive as data on sodium and hypertension, but a high dietary intake of sodium may affect development or severity of some of these conditions. (63)

Possible Adverse Effects of Low Salt Diets

Inadequate sodium or chloride intake

Some studies have reported that low sodium intakes are associated with higher rates of stroke or cardiovascular death and it has been proposed that in industrial societies, the relationship between sodium intake and mortality follows a J-shaped curve. According to this hypothesis, both very low and very high intakes of sodium are associated with greater cardiovascular mortality. Others have suggested that people consuming very low levels of salt may already be sick and that it is the underlying illness rather than the very low sodium intake that causes increased mortality. Low sodium diets may have adverse effects on the sympathetic nervous system, the rennin-angiotension system and insulin sensitivity. (27) Data from NHANES did not demonstrate a significant association between mortality and sodium intake. (28)

The Institute of Medicine recommends that healthy adults (ages 1-50 years) consume 1.5 grams of sodium and 2.3 grams of chloride daily, corresponding to 3.8 grams of salt. At this level, the body would be able to replace the sodium and chloride lost daily through sweat and excretion. But most people greatly exceed these recommendations indicating that moderate reductions in salt intake are probably not of great concern. (73)

Inadequate dietary iodine

Iodine is an important component of thyroid hormones that are required for normal growth, development and metabolism. Most foods are naturally low in iodine with the exception of seafood (fish, shellfish and seaweed). Bread and dairy products have been important dietary sources in the U.S. because of the addition of iodate as a dough conditioner and the use of iodophors for cleaning teats and milk containers. However, the use of both of these compounds has decreased in recent years and people in many industrialized countries now experience mild iodine deficiency. (163;164)

Recommended daily intake of iodine is 150 μg for most adults and 250 μg for pregnant and lactating women. Iodine status of the general U.S. population is considered adequate but there are some subgroups of the population including women of reproductive age and non-Hispanic Blacks who are at risk of iodine deficiency because of their relatively low dietary

iodine intake (NHANES data). In fact, about 29% of U.S. adults are mildly deficient in iodine, and 11% and 2.5% are moderately and severely deficient, respectively. (18;122)

Countries around the world currently add sodium or potassium iodate or iodide to table salt to prevent a variety of iodine-deficiency disorders in adults and children. Iodized salt, contains 77 μg iodine/g in Canada and the U.S. (18) and fortification levels in other countries range from 15 to 100 μg iodine/g. Some iodine is lost from fortified salt during storage and during cooking. Iodized salt is not generally used in processed foods because of concerns about oxidation reactions, color changes, and other issues. (157) Since approximately 80% of dietary salt in Europe and North America comes from processed and restaurant food, reductions in salt levels in processed foods would likely have a minimal impact on iodine intake in these countries.

However, national sodium reduction strategies also encourage consumers to limit the amount of salt added to foods in cooking and at the table. Analysis of some NHANES data indicated that dietary salt restriction was associated significantly lower urinary iodide concentrations in women but not in men. (142) Analyses of food consumption data from the Netherlands indicated that the age group of most concern for iodine sufficiency, if salt intake were significantly reduced, was children (1-3 years of age). (149) Currently, there is no conclusive data indicating that salt restriction will seriously impact iodine status in consumers but with the fairly high prevalence of mild iodine deficiency, this situation should be monitored.

Roles of Salt in Foods

Flavor

Saltiness is one of the basic tastes perceived by humans. Sodium and lithium are the only cations with a taste that is primarily salty. Potassium and calcium, have some component of saltiness to their taste but they also have other flavors, sometimes described as "metallic" or "bitter." Sodium chloride is the saltiest sodium compound. As the size of the anion associated with sodium increases, perceived saltiness decreases.

In addition to their own salty flavor, sodium compounds, such as sodium chloride and monosodium glutamate, enhance the flavor of other ingredients in foods. (129)Salt also suppresses or masks bitter flavors. It has been estimated that about 25% of the population are nontasters (insensitive to ordinary levels of bitter compounds) and about 25% are supertasters (very sensitive to bitter compounds). Therefore, significantly decreasing the salt in some foods may make them unpalatable to as many as a fourth of consumers, while an equal number may not even notice the change. (86)

Sodium chloride affects growth and metabolic activities of cheese starter cultures and yeast and sourdough starters for bread. In addition to their other functions in foods, these microbes synthesize important flavor and aroma compounds (99).

Texture

Sodium chloride interacts with other major components in foods thereby affecting the texture of foods. For example, salt increases hydration of proteins and enhances the binding of proteins to each other and to fat. These reactions stabilize emulsions of ground meat mixed with fat and promote development of a network of gluten proteins in yeast breads.

In meat, 1.5 to 2.5% (w/w) added salt enables proteins to bind more water, thereby increasing tenderness and decreasing fluid loss in heat-processed products. Actin and myosin in meat proteins swell in the presence of salt, binding water and fat and allowing formation of heat-

stable emulsions of comminuted meats, such as frankfurters. These myosin proteins bind to each other thereby improving the texture of processed meats (99;159) and also restructured fish products (120).

Solubility of proteins and the water content of cheese are also affected by salt. These, in turn, determine rheology, texture, and changes that occur during cooking. In pasteurized process cheeses, emulsifying salts (citrate, orthophosphates, polyphosphates), often containing sodium, are added to aid in the hydration of para-casein, emulsification of fats, and stability. (55;81) .

Yeast bread and some other baked goods require some salt to control growth of yeast and develop an extensible gluten network. Salt helps control hydration of glutenin and gliadin proteins which is critical for the development of enough gluten to trap small air bubbles in the dough to produce a high-quality bread. Optimal salt concentrations stabilize gluten and prevent stickiness. Too little salt allows excessive growth of yeast resulting in oversized bread with poor texture. In cakes and quick (non-yeast) breads, salt is added primarily for flavor. However, sodium carbonate and sodium bicarbonate, used for leavening in these products, contribute to the total sodium content. (22;97).

Safety

Salt (sodium chloride) and drying have been used for thousands of years to decrease water activity (a_w) in meat, fish, vegetables, eggs, and some fruit, thereby preserving these fresh foods for later consumption. Available water is a critical factor affecting microbial growth on and in foods. Fresh foods, process cheese, and low-salt bacon have a high a_w (0.95 to 1.0), as do highly perishable foods such as fresh meat and fish (a_w >0.99) (25). Consequently, there is sufficient water to support growth of most bacterial pathogens and spoilage organisms if other conditions do not limit growth. Salt is added to meat and fish particularly as a deterrent to growth of *Clostridim botulinum* (32;120).

On the most basic level, salt preserves food by exerting a drying effect, drawing water out of cells of both the food and microorganisms through the process of osmosis. Salt concentrations required to inhibit microbes vary with species. Campylobacters are highly sensitive to salt, with 0.5% NaCl being optimal for growth (38). On the other hand, proteolytic *C. botulinum* tolerate up to 10% NaCl and, when other growth conditions are favorable, *Staphylococcus aureus* can grow in the presence of >20% NaCl. Minimum water activity levels allowing growth of some important foodborne microbes, when other growth conditions are near optimal, are listed in Table 1. At some a_w levels, bacteria are capable of growth but not toxin production. For example, *S. aureus* can grow aerobically at 37 ºC at an a_w of 0.86, but only produces enterotoxin if a_w is at least 0.90 (Baird-Parker 1990).

Table 1 — Approximate minimum water activity values for growth of some foodborne microbes.

Microbe	Minimum water activity	Reference
Campylobacter jejuni	0.98	(38)
Clostridium botulinum B	0.94	(117)
Clostridium botulinum E	0.97	(117)
Escherichia coli	0.95	(101)
Listeria monocytogenes	0.92	(141)
Salmonella spp.	0.95	(25)
Staphylococcus aureus	0.86	(135)

Shelf-stable sauces, processed meats, and cheeses rely, in part, on sodium chloride for safety and preservation. In addition to sodium chloride, other salts, sugars, and proteins in foods decrease available moisture. Hard cheeses, ham, and bacon have a water activity of 0.90 to 0.95(25). Water lost during processing/cooking increases sodium concentrations on a finished product basis. For example, 100-g samples of fresh raw pork belly, raw cured bacon, and cooked bacon contain, respectively, 0.032 g, 0.833 g, and 2.3 g sodium. (Data from USDA National Nutrient Database, http://www.nal.usda.gov/fnic/foodcomp/search/) (115)

Other sodium-containing compounds are also used for food preservation. For example, disodium phosphate is a critical component for safety of shelf-stable pasteurized process cheese products (140) and sodium nitrite is important for preventing growth and toxin production of *C. botulinum* in cured meats (31). Since these compounds, as well as sodium salts of organic acids and other sodium phosphate compounds are added to foods to prevent microbial growth and improve texture, sodium reduction strategies must also consider these sources of added sodium. As noted in Table 2, sodium lactate is the largest potential contributor to sodium content, after sodium chloride. However, formulating certain foods with reduced amounts of these compounds may have a negative effect on food safety.

Table 2 — Amount of sodium contributed by some common sodium-containing additives as compared to that contributed by sodium chloride.

Sodium compound	Typical use	% sodium in compound	mg of Na/100 g food
Chloride	1.5 to 2%	39.34%	590 to 790
Benzoate	0.1%	15.95%	16
Diacetate	0.1 to 0.4%	16.18%	16 to 65
Lactate	1.5 to 3%	20.51%	310 to 620
Propionate	0.3%	23.93%	70
Sorbate	0.3%	17.14%	50
Nitrite	0.012%	33.32%	4
Acid pyrophosphate (SAPP)	0.35%	20.72%	73
Tripolyphosphate (STPP)	0.35%	31.24%	109
Pyrophosphate (TSPP)	0.35%	34.57%	121
Hexametaphosphate (SHMP)	0.35%	22.55%	79

Strategies in Formulation of Reduced-Sodium Foods

Salt plays multiple roles in foods making it difficult to reformulate safe food products that have lower levels of sodium while retaining taste and texture that consumers find acceptable. A recent review discussed a number of strategies and compounds that have been considered for their potential to replace salt in various foods. (40) There has been a progressive increase in patents granted for products that can be used to improve the sensory value of reduced-sodium foods. Recent patents using different approaches to achieve lower salt levels were recently described. (146)

Flavor

Simply reducing the amount of salt (without replacing it with other substance(s) is a potential strategy for foods in which salt is primarily a flavoring. Small stepwise reductions, of 5 to 10%, in levels of sodium chloride in foods are often not even noticed by consumers.

Successful examples include: (a) a 33% reduction in salt levels in cereals in the UK during a 7 yr period; (b) a 33% sodium reduction in Kraft processed cheese; and (c) a reformulation of Heinz products that resulted in an 11 to 18% decrease in sodium levels. These reductions in salt content may be not only tolerated but even better liked than the original food formulation. (86)

Enhancing saltiness of foods may be accomplished by physical or chemical means. Sodium chloride interacts with taste receptors only when it is in solution. Therefore, physical processes that increase the solubility of salt crystals will increase the sensation of saltiness for a given amount of salt. For example, finer salt crystals could be used to coat snack foods to deliver sufficient saltiness with less sodium. Electrostatic coating of chips improves adhesion of small salt particles and may be used to give a more even coating (17).

Peptides from a variety of hydrolyzed proteins and the sweeteners trehalose and thaumatin enhance the salty taste of foods and permit reduction of sodium chloride levels without significantly altering taste. (19;105) One recommended additive that allows reduction of sodium content of foods is monosodium glutamate that provides an umami flavor. (79;86) Salad dressings, soup, and stir-fried pork, produced with less salt and added naturally brewed soy sauce were judged acceptable by consumers (90). Dried bonito (fish) enhances the saltiness and palatability of a Japanese steamed egg custard thereby allowing a reduction in sodium content (100).

Odors of foods also affect perceptions of taste. A recent European study found that salt-associated odors could enhance perception of saltiness. Panelists presented with a series of solutions containing a standard, small amount of salt rated those with aromas such as bacon, cheese, ham, peanuts, and anchovy as saltier than solutions with no added aroma or those that smelled like tomatoes. Solutions with a carrot odor were rated as less salty than the no-aroma solution (93;94). Certain well-selected odors may effectively compensate for changes in taste of low-sodium foods.

Potassium chloride (KCl) is the most common compound used to substitute for the salty taste of sodium chloride (NaCl). However, it usually cannot be used to replace more than 30-40% of the sodium chloride in foods because of metallic or bitter off-flavors. Combinations of potassium chloride and potassium lactate have bee used to reduce salt levels by 30-50% in fermented sausages and salted minced pork. (57;108) Magnesium sulfate, some calcium and ammonium compounds, amino acids, and dipeptides also have a salty taste but, again, it is not a "pure" salt taste and there are off-flavors (86). Other additives may be needed to improve flavor.

A wide variety of "sea salt" preparations are now sold as alternatives to refined salt. Sea salts contain several calcium, potassium, and magnesium compounds and often other minerals that contribute to flavor. Composition of these salts varies with geographic origin and method of harvest. Assays of 38 commercial sea salts revealed that a few had higher concentrations of sodium than ordinary table salt and all contained other minerals that affected flavor and time-intensity of salty taste. (39) Non-sodium minerals constitute nearly 60% of a few varieties of sea salt and their use may significantly reduce sodium intake (86;124). A mineral salt containing 50% sodium chloride and 44.5% potassium chloride, along with calcium and magnesium carbonates and magnesium sulfate was used in the formulation of several meat products. Although it significantly decreased sodium content, these meats were ranked lower than the standard products by a taste panel because of differences in odor, taste, and consistency (133).

Discovery and formulation of "bitter blockers" to reduce objectionable flavors in salt substitutes and low-salt foods are currently the focus of much research. Sweeteners may be used to interfere with the perception of bitter compounds. Dihydroxybenzoic acid and its salts have

been reported to effectively counteract metallic aftertastes without affecting sweetness (102). A review on bitter-masking molecules describes recent advances in the discovery and development of these compounds (95).

Texture

While small reductions in salt content may result in minor alterations in flavor that are acceptable to consumers, lower salt levels may adversely affect texture requiring addition of moisture, fat, gums, polysaccharides, emulsifiers, alginates or other seaweed derivatives (26;49;69;70;78) to maintain a texture similar to the original product. Formulation of low-salt meat batters is technologically challenging because a reduction in sodium chloride levels requires other ionic compounds to replace the water-holding, protein-binding, and fat-binding functions of the salt that is eliminated. Comminuted meat products containing less than 1.5% salt form unstable emulsions with poor texture (159). Potassium, calcium, and magnesium chlorides and several polyphosphate compounds can be used to stabilize meat emulsions in reduced-sodium meats. KCl and NaCl, at equal ionic strengths, interact identically with meat proteins, but calcium and magnesium chlorides are not as effective (5;54).

Lower salt levels can also impact the growth of microbes such as desirable fermentative bacteria and yeast that influence the texture and flavor of some foods. These effects may be mitigated to some extent by changing the amount of yeast or starter culture used and by adjusting mixing and other mechanical processes during manufacture. KCl has similar effects on yeast growth and rheological properties of dough as that of NaCl but its use is limited by its metallic off-flavor (22). In a series of experiments to evaluate characteristics of wheat bread formulated with 0.6, 0.3, and 0% salt compared to the customary level of 1.2%, lower salt concentrations did not significantly impact the rheological properties of the dough, baking quality, or sensory attributes. However, omission of salt completely produced unpleasant flavors and a significant reduction in structural quality of dough and bread (97).

Reducing sodium chloride in cheese presents many challenges as described in a recent review (81). Reductions of up to 0.5% salt in Cheddar cheese and up to 35% in cottage cheese have been judged acceptable by consumers. Partial substitution of KCl for NaCl does not adversely affect starter culture activity or texture, although there are flavor issues with higher potassium concentrations (126). Magnesium chloride and calcium chloride do not appear to be good substitutes for NaCl in cheeses because texture becomes crumbly, soft, or greasy. Protein enrichment, by addition of ultrafiltered whole milk retentate during cheese-making, produces good-quality low-sodium cheeses with a good texture (55).

Complete elimination of emulsifying salts in process cheese products can reduce sodium levels by 20 to 40%. However, the result is a gummy cheese product with separation of oil and water. A careful blending of different cheese ingredients and optimization of processing conditions can produce a more stable product. Other ingredients, such as starches and gums, can also be used to maintain an acceptable cheese spread texture (55).

Safety

If less salt is added to a food, water activity will be increased potentially allowing growth of spoilage and pathogenic microorganisms. On a molar basis, KCl appears to have antimicrobial effects similar to NaCl in some media and food systems. However, challenge studies in specific foods should be done to confirm that that KCl can safely replace NaCl.

Other compounds such as organic acids, bacteriocins, and essential oils from herbs and spices (13;33;34;52;53;108;110;111;125;138) may be useful in ensuring safety and shelf life of low-sodium food products. Effects of these additives should also be assessed in foods as their efficacy may be altered by other food components such as fat.(56)

Sodium/Salt Substitutes and Additives: Safety Concerns

Potassium, calcium, magnesium, and other minerals

Sodium substitutes often contain other minerals, particularly potassium, some of which may have health consequences to some persons if consumed in excess. Dietary reference intakes have been established for dietary minerals and other nutrients by the Institute of Medicine. These are presented in Table 3 below along with indications of adverse effects of excess consumption.

Table 3. Dietary reference intakes for some minerals (72-74)

Mineral	Age/sex	AI (mg/d)	UL (mg/d)	Effects of excess intake
Calcium	31 – 50 (M&F)	1000	2500	Kidney stones, renal insufficiency,
	51-70 (F)	1200	2000	hypercalcemia
	51-70 (M)	1000	2000	
Chloride	19 – 50 (M&F)	2300	3600	Hypertension (with sodium)
	50 – 70 (M&F)	2000	3600	
Iodine	19 – 70 (M&F)	0.15	1.10	Elevated thyroid stimulating hormone
	19 – 50 (pregnant)	0.22	1.10	
Magnesium	19 – 30 (M/F)	400/310	350*	Osmotic diarrhea (from supplements)
	31 – 70 (M/F)	420/320	350*	
Phosphorus	19 – 70 (M&F)	700	4000	Metastatic calcification, interference with calcium absorption
Potassium	19 – 70 (M&F)	4700	None specified	None from food; from supplements, may cause hyper-kalemia and sudden death in those with CKD or diabetes; those taking ACE inhibitors, ARBs and certain diuretics should not take supplements with potassium
Sodium	19 – 50 (M&F)	1500	2300	Hypertension; cardiovascular disease
	50 – 70 (M&F)	1300	2300	

AI = adequate intake; UL = upper limit of intake without adverse effects

*Upper limit is for intake from pharmacological agents. No upper limit from naturally occurring Mg in foods.

Decreases in dietary sodium levels would be beneficial for those with kidney disease but increased intakes of other minerals used as sodium substitutes in foods may be detrimental. Chronic kidney disease (CKD) results in an imbalance of numerous minerals in the body and dietary recommendations advise CKD patients to decrease dietary potassium and phosphate intake since the body can no longer efficiently excrete excess amounts of these minerals. Loss of

kidney function affects serum levels of phosphates, calcium, potassium, and magnesium and this increases risk for calcification of artery walls, cardiac arrhythmias, and other metabolic disturbances. (15;84;88) Overuse of salt substitutes containing potassium chloride may be an issue for dialysis patients.

There is also a reported case of an individual with diabetes and some cardiac health issues who was on a salt-restricted diet and ingested 7-8 teaspoons/day of a salt substitute containing 53% potassium. He developed very high serum potassium levels and near-fatal respiratory failure. (80)

Organic acids

Organic acids have been widely used as preservatives in some foods for many years and, overall, data indicate that these compounds are of low toxicity with little or no genotoxic or carcinogenic potential. Reports of significant adverse reactions are rare. However, four potential issues have been reported. (1) Benzoate appears to provoke hypersensitivity reactions in certain individuals but this does not appear to be common. (2) Several reports indicate that under acidic conditions and during irradiation, small amounts of the known carcinogen, benzene, can form from benzoates. Therefore, benzoates should probably not be used in foods that will also be irradiated. (3) Under some conditions, sorbates have been reported to degrade during long storage times to form genotoxic compounds and sorbates were reported to form mutagens with nitrites. This is considered an unlikely event with current procedures of meat processing. (4) At very high dietary levels (4% of diet) over extended feeding periods, propionates have caused forestomach cancers in rodents. This is very unlikely to occur in humans. Currently available information is summarized below.

Sodium diacetate is an approved GRAS substance for use as an antimicrobial and was approved by FSIS in 2000 for use in meat and poultry products up to a concentration of 0.25% by weight of total formulation (Federal Register 65: 3121-3123 and 65:17128-17129) No adverse reactions have been reported for humans or animals and no recent acceptable daily intake (ADI) has been established. In 1973, FAO stated that up to 15 mg/kg body weight/ day was acceptable. (36) Calcium acetate (diacetate) is also a GRAS substance that is available commercially for use as a thickener and an acidulant. Potassium diacetate has not been designated as GRAS but has demonstrated antimicrobial effects in a meat system. (77)

Sodium and potassium l**actates** are GRAS substances that were approved by FSIS in 2000 for use as antimicrobials in meat and poultry products, singly or in combination, up to a concentration of 4.8% by weight of total formulation (Federal Register 65: 3121-3123 and 65:17128-17129) A 2-yr. study demonstrated no toxic or carcinogenic effects in rats given water containing 0, 2.5, or 5% calcium lactate in drinking water. (98)

Propionates and propionic acid are approved GRAS substances for use in various foods including cheese and bakery products. Use of sodium propionate has no limitations in a variety of food products (including cheeses, soft candies, baked goods, jams, jellies, nonalcoholic beverages) other than current good manufacturing practices (21CFR 184.1784). Acceptable daily intakes have not been established. Propionic acid gives negative results in most genotoxicity assays (12). Tumors developed in the forestomach of rats fed very high levels of propionic acid (4% of total diet) over long periods of time but propionic acid is not considered a carcinogenic risk for humans. (60)

Sodium Benzoate and benzoic acid are GRAS in the U.S. and are permitted in certain foods as antimicrobial or flavoring agents, with current maximum usage level of 0.1% (21CFR 184.1733). CODEX specifies higher permitted levels in some foods such as liquid eggs (0.5%) and semi-preserved fish (0.2%). (http://www.codexalimentarius.net) Benzoates are readily absorbed in the intestine but are rapidly metabolized and excreted. An acceptable daily intake (ADI) of up to 5 mg/kg body weight has been established. (24;112)Under some conditions benzoic acid or benzoates may form small amounts of benzene, a volatile compound with known toxic and carcinogenic effects. This has been reported and during irradiation of a turkey breast roll and ham containing potassium benzoate (161;162).

Hypersensitivity reactions, including dermatitis (118), rhinitis (9), asthma (10;46), have been reported by some individuals. (43) In most cases, reactions appear to be mild-moderate. A few cases of anaphylaxis have been reported. (103;104)

At high dietary levels, (1-3% of diet), benzoate causes toxic effects in rodents but there is no evidence of carcinogenicity. (24;112)

Sorbates and sorbic acid are GRAS in the U.S. when used in accordance with good manufacturing practices (21CFR 182.3640). Sorbic acid and sorbates are reported to exert a very low level of mammalian toxicity. Allowable usage levels depend on the target food and range between 0.1% for fruit preserves (21CFR Part 150) and 0.3% for certain cheeses (21CFR Part 133).

Challenge tests indicate that sorbic acid or sorbates can cause contact urticaria in a small number of people and oral sensitivity has also been demonstrated. (58;134;151)

Neither sorbic acid nor sorbates appear to be carcinogenic in rodent studies with animals fed diets containing as much as 10% sorbic acid in the diet. (151) Sorbic acid and sorbates generally do not produce genotoxic effects. (11;82;109)However, solutions of sodium sorbate stored for several weeks did exhibit weak genotoxic effects,(109;131) possibly due to the formation of a mutagenic degradation product. (82) Some researchers report that high concentrations of sorbic acid and nitrites form mutagens under acidic conditions(pH<3.5). (127) Ascorbate blocks this reaction indicating that cured meat products containing erythorbate or ascorbate would not contain mutagens. reduce nitrosoamine formation, and this would prevent mutagen formation at pH values that mimic gastric conditions should otherwise optimal conditions exist. (44;136)

Flavor enhancers and bitter blockers

Monosodium glutamate is a widely used flavor enhancer that is sometimes regarded with suspicion because of anecdotal evidence and results from some small studies indicating that it may play a role in asthmatic attacks and migraine headaches. However evidence from carefully controlled studies demonstrated that this compound is safe. (79;160)

Some sweeteners, such as thaumatin and trehalose are used as “bitter blockers.” Data indicate that they and many other sweeteners are safe for use in foods. (91;107)

Thickeners and emulsifiers

Inorganic phosphates exhibit a low oral toxicity and humans are considered unlikely to experience adverse effects if total daily phosphorus consumption is <70 mg/kg/day. (155)

Other thickeners and emulsifiers being considered for improving texture in sodium-reduced foods are compounds that are currently approved for use in other foods and are generally regarded as safe. New compounds from novel plant sources should be tested for possible toxic or allergic effects at relevant concentrations. (89;156)

Perspective

Sodium chloride is an important nutrient and an essential ingredient in producing safe foods with acceptable texture and sensory characteristics. However, population surveys indicate that a great majority of people in industrialized societies consume much more than the current recommended amount of sodium chloride. Reduction of sodium levels in the diet is considered one important strategy for reducing prevalence of hypertension and cardiovascular diseases. Other dietary and lifestyle changes, including increased exercise and intake of fruits and vegetables with high potassium levels and reduced intakes of saturated fats, are also important for good health..

In North American and European countries, processed foods and restaurant foods account for about 70 - 80% of dietary intake of sodium. It is probably not necessary, for improving health, to lower salt concentrations in every food as long as overall dietary intake is reduced. Individuals, particularly those who are salt-sensitive, need to control discretionary use of salt during cooking and at meals. However, those who frequently eat restaurant meals and processed foods find it difficult to reduce total sodium intake

Food processors face the challenge of reducing salt content in their foods while still producing safe, palatable, and economical foods. Surveys have demonstrated variation in sodium content in different brands of foods in the same category and in the same foods sold in different countries. This indicates that reductions in sodium levels in many foods is possible. (76) Potassium salts can partially substitute for sodium salts in foods but flavor issues arise if too much potassium is used. Although populations in industrialized countries generally ingest too little potassium, high dietary potassium levels may pose a risk for people with kidney disease. High dietary phosphate is also a concern for those with reduced kidney function. Other substances used in reformulated, low-sodium foods are primarily compounds or extracts that have already been approved for use in foods. They are considered safe at currently used levels but if their usage were to greatly increase, then safety might need to be reconsidered. Some new products, such as plant extracts and hydrolyzed proteins from new sources should be tested for allergenicity as well as toxicity.

Reference List

1. Adrogué HJ and Madias NE. 2008. Sodium and potassium in the pathogenesis of hypertension. N E J Med 356:1966-1978.

2. Al-Solaiman Y, Jesri A, Mountford WK, Lackland DT, Zhao Y, and Egan BM. 2010. Dash lowers blood pressure in obese hypertensives beyond potassium, magnesium and fibre. J Hum Hypertens 24:237-246.

3. Alderman MH. 2006. Evidence relating dietary sodium to cardiovascular disease. J Am Coll Nutr 25:256S-261S.

4. Alderman MH. 2010. Reducing dietary sodium: the case for caution. J Am Med Assoc 303:448-449.

5. Alino M, Grau R, Fuentes A, and Barat JM. 2010. Influence of low-sodium mixtures of salts on the post-salting stage of dry-cured ham process. J Food Engineer 99:198-205.

6. Anderson CAM, Appel LJ, Okuda N, Brown IANJ, Chan Q, Zhao L, Ueshima H, Kesteloot H, Miura K, Curb JD, Yoshita K, Elliott P, Yamamoto ME, and Stamler J. 2010. Dietary sources of sodium in China, Japan, the United Kingdom, and the United States, women and men aged 40 to 59 years: the Intermap Study. J Am Diet Assoc 110:736-745.

7. Ando K, Matsui H, Fujita M, and Fujita T. 2010. Protective effect of dietary potassium against cardiovascular damage in salt-sensitive hypertension: possible role of its antioxidant action. Curr Vascular Pharmacol 8:59-63.

8. Appel LJ, Frohlich ED, Hall JE, Pearson TA, Sacco RL, Seals DR, Sacks FM, Smith SC, Vafiadis DK, and Van Horn LV. 2011. The importance of population-wide sodium reduction as a means to prevent cardiovascular disease and stroke. Circulation 123:ooo-ooo (ahead of print).

9. Asero R. 2001. Perennial rhinitis induced by benzoate intolerance. J Allerg Clin Immunol 107:197.

10. Balatsinou L, Di Gioacchino G, Sabatino G , Cavallucci E, Caruso R, Gabriele E, Ramondo S, Di Giampaolo L, Verna N, and Di Gioacchino M . 2004. Asthma worsened by benzoate contained in some antiasthmatic drugs. Int J Immunopathol Pharmacol 17:225-226.

11. Banerjee TS and Giri AK. 1986. Effects of sorbic acid and sorbic acid-nitrite in vivo on bone marrow chromosomes of mice. Toxicol Lett 31:101-106.

12. Basler A, von der Hude W, and Scheutwinkel M. 1987. Screening of the food additive propionic acid for genotoxic properties. Food Chem Toxicol 25:287-90.

13. Benkeblia N. 2004. Antimicrobial activity of essential oil extracts of various onions (Allium Cepa) and garlic (Allium Sativum). Lebensm Wissensch Technol 37:263-268.

14. Bibbins-Domingo K, Chertow GM, Coxson PG, Moran A, Lightwood JM, Pletcher MJ, and Goldman L. 2010. Projected effect of dietary salt reductions on future cardiovascular disease. New Engl J Med 362:590-599.

15. Block GA. 2010. Screening dialysis patients for vascular calcification. Semin Dialysis 23:271-276.

16. Brown IJ, Tzoulaki I, Candeias V, and Elliott P. 2009. Salt intakes around the world: implications for public health. Int J Epidemiol 38:791-813.

17. Buck VE and Barringer SA. 2007. Factors dominating adhesion of NaCl onto potato chips. J Food Sci 72:E435-E441.

18. Caldwell KL, Miller GA, Young RY, Jain RB, and Jones RL. 2008. Iodine status of the U.S. population, National Health and Nutrition Examination Survey 2003-2004. Thyroid 18:1207-1214.

19. Campagnol PCB, Dos Santos BA, Morgano MA, Terra NN, and Pollonio MAR. 2011. Application of lysine, taurine, disodium inosinate and disodium guanylate in fermented cooked sausages with 50% replacement of NaCl by KCl. Meat Sci 87:239-243.

20. Carbone LD, Bush AJ, Barrow KD, and Kang AH. 2003. The relationship of sodium intake to calcium and sodium excretion and bone mineral density of the hip in postmenopausal African-American and Caucasian women. J Bone Miner Metab 21:415-420.

21. Carlstrom M, Persson AEG, Larsson E, Hezel M, Scheffer PG, Teerlink T, Weitzberg E, and Lundberg JO. 2011. Dietary nitrate attenuates oxidative stress, prevents cardiac and renal injuries, and reduces blood pressure in salt-induced hypertension. Cardiovas Res 89:574-585.

22. Cauvain SP. 2007. Reduced salt in bread and other baked products, p. 283-295. *In* Kilcast D and Angus F (eds.), Reducing salt in foods . CRC Press LLC, Boca Raton FL.

23. Chen J, Gu DF, Huang JF, Rao DC, Jaquish CE, Hixson JE, Chen CS, Chen JC, Lu FH, Hu DS, Rice T, Kelly TN, Hamm LL, Whelton PK, and He J. 2009. Metabolic syndrome and salt sensitivity of blood pressure in non-diabetic people in China: a dietary intervention study. Lancet 373:829-835.

24. Chipley JR. 2005. Sodium benzoate and benzoic acid, p. 11-48. *In* Davidson PM, Sofos JN, and Branen AL (eds.), Antimicrobials in food. Taylor & Francis, New York.

25. Christian JHB. 2000. Drying and reduction of water activity, p. 146-174. *In* Lund BM, Baird-Parker TC, and Gould GW (eds.), The microbiological safety and quality of food. Aspen Publishers, Inc., Gaithersburg MD.

26. Cofrades S, López-López I, Ruiz-Capillas C, Triki M, and Jiménez-Colmenero F. 2011. Quality characteristics of low-salt restructured poultry with microbial transglutaminase and seaweed. Meat Sci 87:373-380.

27. Cohen HW and Alderman MH. 2007. Sodium, blood pressure, and cardiovascular disease. Curr Opinn Cardiol 22:306-310.

28. Cohen HW, Hailpern SM, and Alderman MH. 2008. Sodium intake and mortality follow-up in the third National Health and Nutrition Examination Survey (NHANES III). J Gen Intern Med 23.

29. Cook NR, Cutler JA, Obarzanek E, Buring JE, Rexrode KM, Kumanyika SM, Appel LJ, and Whelton PK. 2007. Long term effects of dietary sodium reduction on cardiovascular disease outcomes: observational follow-up of the trials of hypertension prevention. Brit Med J 334:885-892.

30. Cook NR, Obarzanek E, Cutler JA, Buring JE, Rexrode KM, Kumanyika SK, Appel LJ, and Whelton PK. 2009. Joint effects of sodium and potassium intake on subsequent cardiovascular disease the trials of hypertension prevention follow-up study. Arch Intern Med 169:32-40.

31. Davidson PM and Taylor TM. 2007. Chemical preservatives and natural antimicrobial compounds, p. 713-745. *In* Doyle MP and Beuchat LR (eds.), Food microbiology: fundamentals and frontiers. ASM Press, Washington, DC.

32. Desmond E. 2006. Reducing salt: a challenge for the meat industry. Meat Sci 74:188-196.

33. Devlieghere F, Geeraard F, Versyck KJ, Vandewaetere B, Van Impe J, and Debevere J. 2001. Growth of *Listeria monocytogenes* in modified atmosphere packed cooked meat products:a predictive model. Food Microbiol 18:53-66.

34. Devlieghere F, Vermeiren L, Bontenbal E, Lamers PP, and Debevere J. 2009. Reducing salt intake from meat products by combined use of lactate and diacetate salts without affecting microbial stability. Int J Food Sci Technol 44:337-341.

35. Dickinson KM, Keogh JB, and Clifton P. 2009. Effects of a low-salt diet on flow-mediated dilation in humans. Am J Clin Nutr 89 :485-490.

36. Doores S. 2005. Organic acids, p. 91-142. *In* Davidson PM, Sofos JN, and Branen AL (eds.), Antimicrobials in food. Taylor & Francis, New York.

37. Doyle ME and Glass KA. 2010. Sodium reduction and its effect on food safety, food quality, and human health. Comp Rev Food Sci Food Safety 9:44-56.

38. Doyle MP and Roman D. 1982. Response of *Campylobacter jejuni* to sodium chloride. Appl Environ Microbiol 43:561-565.

39. Drake SL and Drake MA. 2011. Comparison of salty taste and time intensity of sea and land salts from around the world. J Sensor Stud 26:25-34.

40. Dötsch M, Busch J, Batenburg M, Liem G, Tareilus E, Mueller R, and Meijer G. 2009. Strategies to reduce sodium consumption: a food industry perspective . Crit Rev Food Sci Nutr 49:841-851.

41. Eisner BH, Eisenberg ML, and Stoller ML. 2009. Impact of urine sodium on urine risk factors for calcium oxalate nephrolithiasis. J Urol 182:2330-2333.

42. Elliott P, Walker L, Little MP, Blair-West JR, Shade RE, Lee R, Rouquet P, Leroy E, Jeunemaitre X, Ardaillou R, Paillard F, Meneton P, and Denton DA. 2007. Change in salt intake affects blood pressure of chimpanzees - implications for human populations. Circulation 116:1563-1568.

43. Fahrenholz JM and Smith KM. 2008. Adverse reactions to benzoates and parabens, p. 394-402. *In* Food Allergy: Adverse Reactions to Foods and Food Additives.

44. Ferrand C, Marc F, Fritsch P, Cassand P, and Blanquat GD. 2000. Genotoxicity study of reaction products of sorbic acid. J Agr Food Chem 48:3605-3610.

45. Frassetto LA, Morris RC, and Sebastian A. 2007. Dietary sodium chloride intake independently predicts the degree of hyperchloremic metabolic acidosis in healthy humans consuming a net acid-producing diet. Am J Physiol-Renal Physiol 293:F521-F525.

46. Freedman BJ. 1977. Asthma induced by sulphur dioxide, benzoate and tartrazine contained in orange drinks. Clin Allerg 7:407-15.

47. Frings-Meuthen P, Baecker N, and Heer M. 2008. Low-grade metabolic acidosis may be the cause of sodium chloride-induced exaggerated bone resorption. J Bone Miner Res 23:517-524.

48. Fung TT, Chiuve SE, McCullough ML, Rexrode KM, Logroscino G, and Hu FB. 2008. Adherence to a DASH-style diet and risk of coronary heart disease and stroke in women. Arch Intern Med 168:713-720.

49. García-García E and Totosaus A. 2008. Low-fat sodium-reduced sausages: effect of the interaction between locust bean gum, potato starch and kappa-carrageenan by a mixture design approach. Meat Sci 78:406-413.

50. Geleijnse JM, Witteman JC, Stijnen T, Kloos MW, Hofman A, and Grobbee DE . 2007. Sodium and potassium intake and risk of cardiovascular events and all-cause mortality: the Rotterdam Study. Eur J Epidemiol 22:763-770.

51. Gillespie C, Kuklina EV, Briss PA, Blair NA, and Hong Y. 2011. Vital signs: prevalence, treatment, and control of hypertension - United States, 1999-2002 and 2005-2008. Morbid Mortal Weekly Rep 60:103-108.

52. Glass K, Preston D, and Veesenmeyer J. 2007. Inhibition of *Listeria monocytogenes* in turkey and pork-beef bologna by combinations of sorbate, benzoate, and propionate. J Food Prot 70:214-217.

53. Glass KA, McDonnell LM, Rassel RC, and Zierke KL. 2007. Controlling *Listeria monocytogenes* on sliced

ham and turkey products using benzoate, propionate, and sorbate. J Food Prot 70:2306-2312.

54. Gordon A and Barbut S. 1992. Mechanisms of meat batter stabilization. Crit Rev Food Sci Nutr 32:299-332.

55. Guinee TP and O'Kennedy BT. 2007. Reducing salt in cheese and dairy spreads, p. 316-357. *In* Kilcast D and Angus F (eds.), Reducing salt in foods. Woodhead Publishing Ltd., CRC Press LLC.

56. Gupta S and Ravishankar S. 2005. A comparison of the antimicrobial activity of garlic, ginger, carrot, and turmeric pastes against *Escherichia coli* O157:H7 in laboratory buffer and ground beef. Foodborne Pathog Dis 2:330-340.

57. Guàrdia MD, Guerrero L, Gelabert J, Gou P, and Arnau J. 2008. Sensory characterisation and consumer acceptability of small calibre fermented sausages with 50% substitution of NaCl by mixtures of KCl and potassium lactate. Meat Sci 80:1225-1230.

58. Hannuksela M and Haahtela T. 1987. Hypersensitivity reactions to food additives. Allergy 42:561-575.

59. Harnden KE, Frayn KN, and Hodson L. 2010. Dietary approaches to stop hypertension (DASH) diet: applicability and acceptability to a UK population. J Human Nutr Diet 23:3-10.

60. Harrison PT . 1992. Propionic acid and the phenomenon of rodent forestomach tumorigenesis: a review. Food Chem Toxicol 30:333-340.

61. He FJ and MacGregor GA. 2007. Dietary salt, high blood pressure and other harmful effects on health, p. 18-54. *In* Kilcast D and Angus F (eds.), Reducing salt in foods. CRC Press, New York.

62. He FJ and MacGregor GA. 2009. A comprehensive review on salt and health and current experience of worldwide salt reduction programmes. J Human Hyperten 23:363-384.

63. He FJ and MacGregor GA. 2010. Reducing population salt intake worldwide: from evidence to implementation. Prog Cardiovasc Dis 52:363-382.

64. He FJ, Marciniak M, Carney C, Markandu ND, Anand V, Fraser WD, Dalton RN, Kaski JC, and MacGregor GA. 2010. Effects of potassium chloride and potassium bicarbonate on endothelial function, cardiovascular risk factors, and bone turnover in mild hypertensives. Hypertension 55:681-688.

65. He FJ, Marciniak M, Visagie E, Markandu ND, Anand V, Dalton RN, and MacGregor GA. 2009. Effect of modest salt reduction on blood pressure, urinary albumin, and pulse wave velocity in white, black, and Asian mild hypertensives. Hypertension 54:482-488.

66. He J, Gu DF, Chen J, Jaquish CE, Rao DC, Hixson JE, Chen JC, Duan XF, Huang JF, Chen CS, Kelly TN, Bazzano LA, and Whelton PK. 2009. Gender difference in blood pressure responses to dietary sodium intervention in the Gensalt study. J Hyperten 27:48-54.

67. Heaney RP. 2006. Role of dietary sodium in osteoporosis. J Am Coll Nutr 25:271S-276S.

68. Hollenberg NK. 2006. The influence of dietary sodium on blood pressure. J Am Coll Nutr 25:240S-246S.

69. Hong GP and Chin KB. 2010. Effects of microbial transglutaminase and sodium alginate on cold-set gelation of porcine myofibrillar protein with various salt levels. Food Hydrocolloids 24:444-451.

70. Hong GP and Chin KB. 2010. Evaluation of sodium alginate and glucono-delta-lactone levels on the cold-set gelation of porcine myofibrillar proteins at different salt concentrations. Meat Sci 85:201-209.

71. Huggins CE, Margerison C, Worsley A, and Nowson CA. 2011. Influence of dietary modifications on the

blood pressure response to antihypertensive medication. Brit J Nutr 105:248-255.

72. Institute of Medicine. 1997. Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D and fluoride. National Academies Press, Washington D.C. http://www.iom.edu/Reports/1997/Dietary-Reference-Intakes-for-Calcium-Phosphorus-Magnesium-Vitamin-D-and-Fluoride.aspx

73. Institute of Medicine. 2004. Dietary reference intakes for water, potassium, sodium, chloride, and sulfate. National Academies Press, Washington, D.C. http://www.iom.edu/~/media/Files/Activity%20Files/Nutrition/DRIs/DRI_Electrolytes_Water.pdf

74. Institute of Medicine. 2010. Dietary reference values for calcium and vitamin D. National Academies Press, Washington D.C. http://www.iom.edu/Reports/2010/Dietary-Reference-Intakes-for-Calcium-and-Vitamin-D.aspx

75. Intersalt Cooperative Research Group. 1988. Intersalt: an international study of electrolyte excretion and blood pressure. Brit Med J 297:319-328.

76. Jeffrey B and Cappello N. 2009. Salty to a Fault. Center for Science in the Public Interest, Ottawa.

77. Jensen JM, Robbins KL, Ryan KJ, Homco-Ryan C, McKeith FK, and Brewer MS. 2003. Effects of lactic and acetic acid salts on quality characteristics of enhanced pork during retail display. Meat Sci 63:501-508.

78. Jiménez-Colmenero F, Cofrades S, López-López I, Ruiz-Capillas C, Pintado T, and Solas MT. 2010. Technological and sensory characteristics of reduced/low-fat, low-salt frankfurters as affected by the addition of konjac and seaweed. Meat Sci 84:356-363.

79. Jinap S and Hajeb P. 2010. Glutamate: its applications in food and contribution to health. Appetite 55:1-10.

80. John S and Koff M. 2009. No salt, no danger? A unique case of near-fatal hyperkalemia from salt-substitute. Crit Care Med 37:A 513 .

81. Johnson ME, Kapoor R, McMahon DJ, McCoy DR , and Narasimmon RG. 2009. Reduction of sodium and fat levels in natural and processed cheeses: scientific and technological aspects. Comp Rev Food Sci Food Safety 8:252-268.

82. Jung R, Cojocel C, Müller W, Böttger D, and Lück E. 1992. Evaluation of the genotoxic potential of sorbic acid and potassium sorbate. Food Chem Toxicol 30:1-7.

83. Kanbay M, Chen YB, Solak Y, and Sanders PW. 2011. Mechanisms and consequences of salt sensitivity and dietary salt intake. Curr Opin Nephrol Hyperten 20:37-43.

84. Kanbay M, Goldsmith D, Uyar ME, Turgut F, and Covic A. 2010. Magnesium in chronic kidney disease: challenges and opportunities. Blood Purification 29:280-292.

85. Katz B and Williams LA. 2010. Salt reduction gains momentum. Food Technol 64:24-27, 29-32.

86. Kilcast D and den Ridder C. 2007. Sensory issues in reducing salt in food products, p. 201-220. *In* Kilcast D and Angus F (eds.), Reducing salt in foods. CRC Press LLC, Boca Raton FL.

87. Kimura G, Dohi Y, and Fukuda M. 2010. Salt sensitivity and circadian rhythm of blood pressure: the keys to connect CKD with cardiovasucular events. Hypertension Res 33:515-520.

88. Korgaonkar S, Tilea A, Gillespie BW, Kiser M, Eisele G, Finkelstein F, Kotanko P, Pitt B, and Saran R. 2010. Serum potassium and outcomes in CKD: insights from the RRI-CKD cohort study. Clin J Am Soc Nephrol 5:762-769.

89. Kralova I and Sjoblom J. 2009. Surfactants used in food industry: a review. J Dispersion Sci Technol 30:1363-1383.

90. Kremer S, Mojet J, and Shimojo R. 2009. Salt reduction in foods using naturally brewed soy sauce. J Food Sci 74:S255-S262.

91. Kroger M, Meister K, and Kava R. 2006. Low-calorie sweeteners and other sugar substitutes: a review of the safety issues. Comp Rev Food Sci Food Safety 5:35-47.

92. Laatikainen T, Pietinen P, Valsta L, Sundvall J, Reinivuo H, and Tuomilehto J. 2006. Sodium in the Finnish diet: 20-year trends in urinary sodium excretion among the adult population. Eur J Clin Nutr 60:965-970.

93. Lawrence G, Salles C, Palicki O, Septier C, Busch J, and Thomas-Danguin T. 2011. Using cross-modal interactions to counterbalance salt reduction in solid foods. Int Dairy J 21:103-110.

94. Lawrence G, Salles C, Septier C, Busch J, and Thomas-Danguin T. 2009. Odour-taste interactions: a way to enhance saltiness in low-salt content solutions. Food Quality and Preference 20:241-248.

95. Ley JP. 2008. Masking bitter taste by molecules. Chemosensory Perception 1:58-77.

96. Lin PH, Ginty F, Appel LJ, Aickin M, Bohannon A, Garnero P, Barclay D, and Svetkey LP. 2003. The DASH diet and sodium reduction improve markers of bone turnover and calcium metabolism in adults. J Nutr 133:3130-3136.

97. Lynch EJ, Bello FD, Sheehan EM, Cashman KD, and Arendt EK. 2009. Fundamental studies on the reduction of salt on dough and bread characteristics. Food Res Int 42:885-891.

98. Maekawa A, Matsushima Y, Onodera H, Shibutani M, Yoshida J, Kodama Y, Kurokawa Y, and Hayashi Y. 1991. Long-term toxicity/carcinogenicity study of calcium lactate in F344 rats. Food Chem Toxicol 29:589-594.

99. Man CMD. 2007. Technological functions of salt in food products, p. 157-173. *In* Kilcast D and Angus F (eds.), Reducing salt in foods . CRC Press LLC, Boca Raton FL.

100. Manabe M. 2008. Saltiness enhancement by the characteristic flavor of dried bonito stock. J Food Sci 73:S321-S325.

101. Marshall BJ, Ohye DF, and Christian JH. 1971. Tolerance of bacteria to high concentrations of NaCl and glycerol in growth medium. Appl Microbiol 21:363-364.

102. McGregor R. 2007. The use of bitter blockers to replace salt in food products, p. 221-230. *In* Kilcast D and Angus F (eds.), Reducing Salt in Foods: Practical Strategies. Woodhead Publishing Ltd , Cambridge, UK .

103. Michils A, Vandermoten G, Duchateau J, and Yernault JC. 1991. Anaphylaxis with sodium benzoate. Lancet 337:1424-1425.

104. Moneret-Vautrin DA, Moeller R, Malingrey L, and Laxenaire MC. 1982. Anaphylactoid reaction to general anaesthesia: a case of intolerance to sodium benzoate. Anaesthes Intens Care 10:156-157.

105. Morris C, Labarre C, Koliandris AL, Hewson L, Wolf B, Taylor AJ, and Hort J. 2010. Effect of pulsed delivery and bouillon base on saltiness and bitterness perceptions of salt delivery profiles partially substituted with KCl. Food Qual Prefer 21:489-494.

106. Morris RC, Schmidlin O, Frassetto LA, and Sebastian A. 2006. Relationship and interaction between sodium and potassium. J Am Coll Nutr 25:262S-270S.

107. Mortensen A. 2006. Sweeteners permitted in the European Union: safety aspects. Scan J Food Nutr 50:104-116.

108. Muñoz I, Arnau J, Costa-Corredor A , and Gou P. 2009. Desorption isotherms of salted minced pork using K-lactate as a substitute for NaCl. Meat Sci 83:642-646.

109. Münzner R, Guigas C, and Renner HW. 1990. Re-examination of potassium sorbate and sodium sorbate for possible genotoxic potential. Food Chem Toxicol 28:397-401.

110. Nadarajah D, Han JH, and Holley RA. 2005. Inactivation of *Escherichia coli* O157:H7 in packaged ground beef by allyl isothiocyanate. Int J Food Microbiol 99:269-279.

111. Nadarajah D, Han JH, and Holley RA. 2005. Use of mustard flour to inactivate *Escherichia coli* O157:H7 in ground beef under nitrogen flushed packaging. Int J Food Microbiol 99:257-267.

112. Nair B. 2001. Final report on the safety assessment of benzyl alcohol, benzoic acid, and sodium benzoate. Int J Toxicol 20:23-50.

113. Ni Mhurchu C, Capelin C, Dunford EK, Webster JL, Neal BC, and Jebb SA. 2011. Sodium content of processed foods in the United Kingdom: analysis of 44,000 foods purchased by 21,000 households. Am J Clin Nutr 93:594-600.

114. Nouvenne A, Meschi T, Prati B, Guerra A, Allegri F, Vezzoli G, Soldati L, Gambaro G, Maggiore U, and Borghi L. 2010. Effects of a low-salt diet on idiopathic hypercalciuria in calcium-oxalate stone formers: a 3-mo randomized controlled trial. Am J Clin Nutr 91:565-570.

115. Nummer BA and Andress EL. Curing and smoking meats for home food preservation literature review and critical preservation points. 2002. University of Georgia, Cooperative Extension Service. 2009. http://www.uga.edu/nchfp/publications/nchfp/lit_rev/cure_smoke_intro.html

116. Obligado SH and Goldfarb DS. 2008. The association of nephrolithiasis with hyperension and obesity: a review. Am J Hyperten 21:257-264.

117. Ohye DF and Christian JHB. 1967. Combined effects of temperature, pH, and water activity on growth and toxin production by *Clostridium botulinum* types A, B, and E , p. 217-223. *In* Ingram M and Roberts TA (eds.), Botulism, 1966. Chapman and Hall, London.

118. Ortolani C and Ispano M. 1992. Foods and chronic urticaria. Clin Rev Allerg 10:325-47.

119. Pase MP, Grima NA, and Sarris J. 2011. The effects of dietary and nutrient interventions on arterial stiffness: a systematic review. Am J Clinl Nutr 93:446-454.

120. Pedro S and Nunes ML. 2007. Reducing salt in seafood products, p. 256-282. *In* Kilcast D and Angus F (eds.), Reducing salt in foods. CRC Press LLC, Boca Raton FL.

121. Peralez GJ, Kuklina EV, Keenan NL, and Labarthe DR. 2010. Sodium intake among adults - United States, 2005-2006. Morbid Mortal Weekly Rep 59:746-749.

122. Perrine CG, Herrick K, Serdula MK, and Sullivan KM. 2010. Some subgroups of reproductive age women in the United States may be at risk for iodine deficiency. J Nutr 140:1489-1494.

123. Pimenta E, Gaddam KK, Oparil S, Aban I, Husain S, Dell'Italia LJ, and Calhoun DA. 2009. Effects of dietary sodium reduction on blood pressure in subjects with resistant hypertension: results from a randomized trial. Hypertension 54:475-481.

124. Pszczola DE. 2007. Savoring the possibilities. Food Technol 61:55-66.

125. Raybaudi-Massilia RM, Mosqueda-Melgar J, and Martin-Belloso O. 2006. Antimicrobial activity of essential oils on *Salmonella enteritidis*, *Escherichia coli*, and *Listeria innocua* in fruit juices. J Food Prot 69:1579-1586.

126. Reddy KA and Marth EH. 1995. Microflora of cheddar cheese made with sodium chloride, potassium chloride, or mixtures of sodium and potassium chloride. J Food Prot 58:54-61.

127. Robach MC and Sofos JN. 1982. Use of sorbates in meat products, fresh poultry and poultry products: a review. J Food Prot 45:374-383.

128. Sacks FM, Svetkey LP, Vollmer WM, Appel LJ, Bray GA, Harsha D, Obarzanek E, Conlin PR, Miller ER 3rd, Simons-Morton DG, Karanja N, and Lin PH. 2001. Effects on blood pressure of reduced dietary sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. DASH-Sodium Collaborative Research Group. N Engl J Med 344:3-10.

129. Saint-Eve A, Lauverjat C, Magnan C, Déléris I, and Souchon I. 2009. Reducing salt and fat content:impact of composition, texture and cognitive interactions on the perception of flavored model cheeses. Food Chem 116:167-175.

130. Sanada H, Jones JE, and Jose PA. 2011. Genetics of salt-sensitive hypertension. Curr Hypertension Rep 13:55-66.

131. Schiffmann D and Schlatter J. 1992. Genotoxicity and cell transformation studies with sorbates in Syrian hamster embryo fibroblasts. Food Chem Toxicol 30:669-672.

132. Schmidlin O, Forman A, Sebastian A, and Morris RC. 2007. What initiates the pressor effect of salt in salt-sensitive humans? - observations in normotensive blacks. Hypertension 49:1032-1039.

133. Schoene F, Mnich K, Jahreis G/Kinast C, Greiling A, Kirmse R, Hartung H, and Leiterer M. 2009. Analysis of meat products, produced with mineral salt. constituents and sensory assessment of meat articles produced with a mineral salt compared with common salt. Fleischwirtschaft 89:149-152.

134. Schultz-Ehrenburg U and Gilde O . 1987. Results of studies in chronic urticaria with special reference to nutritional factors [German]. Zeitschrift fur Hautkrankheiten 62:88-95.

135. Scott WJ. 1953. Water relations of *Staphylococcus aureus* at 30°C. Aust J Biol Sci 6:549-564.

136. Scotter MJ and Castle L. 2004. Chemical interactions berween additives in foodstuffs: a review. Food Additiv Contam 21:93-124.

137. Sebastian A, Frassetto LA, Sellmeyer DE, Merriam RL, and Morris RC. 2002. Estimation of the net acid load of the diet of ancestral preagricultural *Homo sapiens* and their hominid ancestors. Am J Clin Nutr 76:1308-1316.

138. Seman DL, Quickert SC, Borger AC, and Meyer JD. 2008. Inhibition of *Listeria monocytogenes* growth in cured ready-to-eat meat products by use of sodium benzoate and sodium diacetate. J Food Prot 71:1386-1392.

139. Strazzullo P, D'Elia L, Kandala NB, and Cappuccio FP. 2009. Salt intake, stroke, and cardiovascular disease: meta-analysis of prospective studies. Brit Med J 339.

140. Tanaka N, Traisman E, Plantinga P, Finn L, Flom W, Meske L, and Guggisberg J. 1986. Evaluation of factors involved in antibotulinal properties of pasteurized process cheese spreads. J Food Prot 49:526-531.

141. Tapia De Daza *MS, Villegas Y, and Martinez A. 1991. Minimal water activity for growth of* Listeria monocytogenes as affected by solute and temperature. Int J Food Microbiol 14:333-337.

142. Tayie FAK and Jourdan K. 2010. Hypertension, dietary salt restriction, and iodine deficiency among adults. Am J Hyperten 23:1095-1102.

143. Taylor EN, Fung TT, and Curhan GC. 2009. DASH-style diet associates with reduced risk for kidney stones. J Am Soc Nephrol 20:2253-2259.

144. Teucher B, Dainty JR, Spinks CA, Majsak-Newman G, Berry DJ, Hoogewerff JA, Foxall RJ, Jakobsen J, Cashman KD, Flynn A, and Fairweather-Tait SJ. 2008. Sodium and bone health: the impact of moderately high and low salt intakes on calcium metabolism in postmenopausal women. J Bone Miner Res 23:1477-1485.

145. Todd AS , MacGinley RJ, Schollum JBW, Johnson RJ, Williams SM, Sutherland WHF, Mann J I, and Walker RJ. 2010. Dietary salt loading impairs arterial vascular reactivity. Am J Clin Nutr 91:557-564.

146. Toldrá F and Barat JM. 2009. Recent patents for sodium reduction in foods. Rec Patents Food Nutr Agr 1:80-86.

147. U.S. Department of Agriculture and U.S. Department of Health and Human Services. 2010. *Dietary Guidelines for Americans, 2010*. U.S.Government Printing Office, Washington, DC. http://www.cnpp.usda.gov/Publications/DietaryGuidelines/2010/PolicyDoc/PolicyDoc.pdf

148. Van Vliet BN and Montani JP. 2008. The time course of salt-induced hypertension, and why it matters. Int J Obesity 32 Suppl. 6:S35-S47.

149. Verkaik-Kloosterman J, Van 't Veer P, and Ocke MC. 2010. Reduction of salt: will iodine intake remain adequate in the Netherlands? Br J Nutr 104:1712-1718.

150. Walker J, MacKenzie AD, and Dunning J. 2007. Does reducing your salt intake make you live longer? Interact Cardiovasc Thorac Surg 6:793-798.

151. Walker R. 1990. Toxicology of sorbic acid and sorbates. Food Additiv Contamin 7:671-6.

152. Webster J, Dunford E, Huxley R, Li N, Nowson CA, and Neal B. 2009. The development of a national salt reduction strategy for Australia. Asia Pac J Clin Nutr 18:303-309.

153. Webster JL, Dunford EK, and Neal BC. 2010. A systematic survey of the sodium contents of processed foods. Am J Clin Nutr 91:413-420.

154. Weinberger MH, Fineberg NS, Fineberg SE, and Weinberger M. 2001. Salt sensitivity, pulse pressure, and death in normal and hypertensive humans. Hypertension 37:429-432.

155. Weiner M, Salminen WF, Larson PR, Barter RA, Kranetz JL, and Simon GS. 2001. Toxicological review of inorganic phosphates. Food Chem Toxicol 39:759-786.

156. WHO/FAO. 2008. Safety evaluation of certain food additives and contaminants. WHO Food Additives Series 471pp.

157. Winger RJ, König J, and House DA. 2008. Technological issues associated with iodine fortification of foods. Trends Food Sci Technol 19:94-101.

158. Wynn E, Krieg MA, Lanham-New SA, and Burckhard P. 2010. Positive influence of nutritional alkalinity on bone health. Proc Nutr Soc 69:166-173.

159. Xiong YL. 2007. Meat binding: emulsions and batters . American Meat Science Association, Savoy IL.

160. Yoneda J, Chin K, Torii K, and Sakai R. 2011. Effects of oral monosodium glutamate in mouse models of asthma. Food Chem Toxicol 49:299-304.

161. Zhu MJ, Mendonca A, Ismail HA, Du M, Lee EJ, and Ahn DU. 2005. Impact of antimicrobial ingredients and irradiation on the survival of Listeria monocytogenes and the quality of ready-to-eat turkey ham. Poultr Sci 84:613-620.

162. Zhu MJ, Mendonca A, Min B, Lee EJ, Nam KC, Park K, Du M, Ismail HA, and Ahn DU. 2004. Effects of electron beam irradiation and antimicrobials on the volatiles, color, and texture of ready-to-eat turkey breast roll. J Food Sci 69:C382-C387.

163. Zimmermann MB. 2009. Iodine deficiency. Endocrine Rev 30:376-408.

164. Zimmermann MB. 2010. Iodine deficiency in industrialised countries. Proc Nutr Soc 69:133-143.