Looking for My Lost Shaker of Salt… Replacer: Flavor, Function, Future

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- This timely Hot Topic Session on salt and sodium was held at the AACC International Annual Meeting in Savannah, GA, U.S.A., on October 27, 2010.
- At the session, a review of the latest research and legislation was provided and is summarized here.
- This article outlines the challenges and factors related to sodium reduction.

Salt and sodium are currently one of the top issues for healthy reformulation efforts by food and beverage manufactures on a global basis. Sodium consumption on average has increased to the point of exceeding an average daily consumption of 3,500 mg. In most countries, the source of sodium in the diet is not the salt shaker. Over 70% of the sodium in the diet is coming from processed foods, for which the consumer has little control as to the level of sodium that is present. As the cost of health care rises, with cardiovascular disease as a primary cause, health experts and leaders are looking for ways to improve the health of their nations. The spotlight, rightly or wrongly, has been placed on the reduction of sodium.

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The challenges and factors related to sodium reduction are diverse. Salt provides the single highest concentration of dietary sodium in most food products. Salt has a number of key functions in food, including food preservation and interaction with gluten to provide bake performance and flavor optimization. Salt is not the only source of sodium; there are other functional ingredients that also contribute sodium, some for which there are no effective sodium-free replacements. The challenges to sodium reduction are many, including the consideration that alternatives to salt- and sodium-based functional ingredients may be more costly. Labeling claims are confusing at best. Sea salts exist, but there is neither a definition for nor consistency in composition. Sea salts can consist of a variety of chloride salts, including sodium, potassium, magnesium, and ammonium, depending on the source sea from which it is harvested. Alternate salts, for example potassium, have not been fully vetted for their health implications. The regulatory picture is becoming uncertain as the FDA gears up to assess salt as a generally recognized as safe (GRAS) ingredient and the USDA looks at lowering the dietary guideline for sodium. Interest groups, such as the Center for Science in the Public Interest (CSPI), and health organizations like the Institute of Medicine (IOM) are also taking stands on the subjects of salt and sodium in food.

A Hot Topic Session was held at the AACC International Annual Meeting in October 2010 to explore key subject matter related to the challenges of salt and sodium reduction. Session participants and topics included Diane Ray, vice president of strategic innovation, Natural Marketing Institute (NMI)—A spoon of salt in a glass of water makes the water undrinkable. A spoon of salt in a lake is almost unnoticed. Market drivers and trends—Consumer impact; Kari Ryan, group manager, nutrition science and regulatory affairs, Frito-Lay, Inc.— Physiology—Health and nutritional aspects of sodium in the diet; Sarah Roller, partner and chair, food and drug law practice, Kelley, Drye & Warren—Regulating salt and other dietary sources of sodium to promote public health: The global policy landscape and outlook; Peter Koehler, vice director, German Research Center for Food Chemistry—Sodium functionality in bakery applications—Technological and sensory aspects; Jean Weber, senior technology manager, ingredient technology group, G-Tech, General Mills—Challenges and strategies for sodium reduction; and Martijn Noort, project manager and bakery scientist, Food and Biotechnology Innovations Department, TNO—Strategies for improving the sensory profile of sodium-reduced foods.

Salt/Sodium: The Consumer Perspective

Salt has played a critical role in the development of human civilization. Food preservation, metal working, and ceremonial uses have all contributed to the prevalence and easy accessibility of salt and today's acquired taste preferences. While sodium has been branded "bad" for our diets, salt is, in fact, a requirement of our physical well being. Healthy 19–50 year olds should consume 1.5 g of sodium and 2.3 g of chloride each day—or 3.89 g of salt—to replace the amount lost daily on average through sweat and excretion and to achieve a diet that provides sufficient amounts of other essential nutrients (1). Sodium helps to maintain the body's fluids. Too much sodium can cause too much fluid in the body, which in turn can impact blood pressure and lead to damage. The average consumer does not understand the difference between salt and sodium, much less between sodium salts, potassium salts, and magnesium salts and this is just the beginning of consumer confusion.

Consumers are bombarded with conflicting information from the *Journal of the American Medical Association* stating there is "limited proof of the problem" to salt vendors touting benefits of Bolivian Salt, Gray Salt, Sea Salt, Celtic Salt, etc. Consumers don't understand where there are benefits and where there is harm—and who could blame them for simplifying to "salt is bad"?

Consumers have heard and internalized the "salt is bad" message. Forty-three percent of the general population, or about 100 million people, say they would like to get less sodium or eliminate sodium from their diets. Women and more health-conscious consumers ("WELLBEINGS" represent 19% of the general population and the most health conscious of NMI health and wellness consumer segments) are even more likely to be concerned about sodium than men or non-health conscious consumers ("EAT, DRINK, AND BE MERRYS" represent 22% of the general population) (Fig. 1) (2). ("WELLBEINGS" and "EAT, DRINK, AND BE MERRYS" are registered trademarks of NMI.)

Although there is some variation by country, approximately 70% of dietary sodium comes from processed foods and restaurant foods. In the United States, the level is 77% (3); in Australia, the level is 88% from processed foods (4); in Europe, the European Foods Safety Authority (EFSA) estimates that 70–75% of the sodium in the diet is from processed foods (5); and in Japan, about 63% comes from processed food and soy sauce (6). Only in China do we see that it is discretionary sources of sodium, those added during cooking and at the table, that account for the primary source of sodium in the diet (76%) (6).

Consumer health is of concern to individuals and is a matter of public policy. Twenty-seven percent of the adult general population, or about 63 million Americans, say they are actively managing or treating salt intake and this is up from 19% five years ago (2). Physicians tell consumers "eat less salt!" Managing sodium consumption is not as simple as "eating less." We know that consumers managing sodium intake are also managing weight, diabetes, and heart and joint conditions (Table I), and this is linked to a strong body of evidence showing the role of sufficient magnesium levels in preventing and managing disorders, such as HTN, cardiovascular disease, and diabetes (7).

Many foods consumers eat may not even taste salty. Although a product may not taste salty, for example, bread, without salt in its formulation, is described as bland. Consumers often exchange salty for sweet in their palate without understanding the real trade-offs. While one's health can be complex, the product choices one faces are also a challenge. Market drivers for convenience and health are at a divergence. Processed food is more convenient, yet as we further process food, the level of sodium increases. Figure 2 illustrates how going from a simple tomato with a natural level of sodium of 15 mg through a number of processing steps leads to tomato soup with a sodium level of 950 mg (8). All the while,

Table I. Sodium links to multiple health conditions (2)

	General Population (%)	Household Treating/ Mng Sodium (%)	Index
Heart	43	76	177
Lose wt. for health	41	68	166
Sugar	30	66	220
Joint pain	40	60	150
Lack of energy	30	44	147
Stress	30	42	140
Osteo/bone	17	31	182

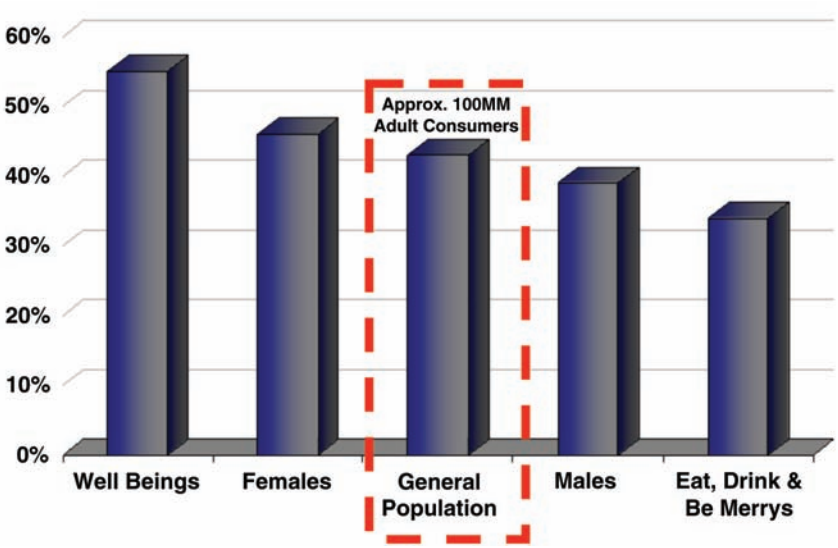

Fig. 1. Percent of U.S. primary grocery shoppers saying they wish to eliminate or reduce sodium in their diets (2).

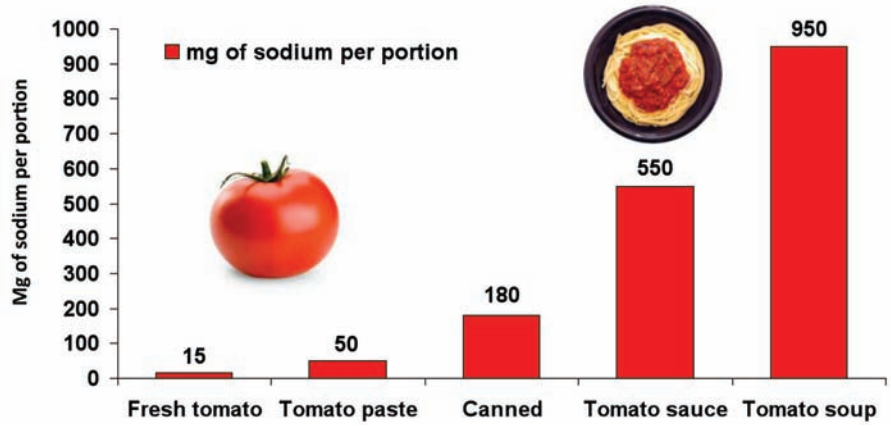

Fig. 2. Processed foods play a major role as a source of sodium; more processing usually means more sodium (8).

the consumer perception is that tomatoes are healthy. For the consumer, it's not as easy as meat pizza at 2,400 mg of sodium per serving versus organic granola at 0 mg of sodium per serving—sodium resides in many foods you do not think of as salty. A plain bagel for instance can have as much as 790 mg of sodium—almost one-third of the daily recommended supply for adults!

Consumer labeling is at its worst in regard to confusion when a manufacturer cites "reduced sodium" when the product still contains very high levels—just less than before. Reduced-sodium, less-sodium, and low-sodium claims can be misleading and misunderstood. Sodium is fast emerging as a top concern for consumers on the nutrition label, second only to calories and now higher than fat (Table II) (9) but few can articulate how much *enough* is and what they are consuming in various foods. Seventy-one percent of consumers don't know the recommended daily amount of sodium intake (10). It is this confusion that leads to front of package labeling solutions like those used in Canada and the United Kingdom, giving the consumer an idea about consumption of the food and potential health risks.

All this confusion aside, consumers do vote with their dollars. Sixty-nine percent of grocery shoppers say they have purchased low/reduced sodium foods in the last year and, of this group, 30% say they have increased their use of these low/reduced sodium products (2). The demand for these products has been recognized by manufacturers and in the past year (52 weeks ending October 15, 2010), 919 low-sodium baking products have been introduced, and 186 low-sodium breakfast cereal products and 5,440 low-sodium food/beverage products were introduced in the United States alone. Globally, low-sodium product introductions for the same time period are 5,414; 1,086; and 36,171, respectively (11).

Consumers are getting too much sodium in their diets. This appears to be a universal concern; the U.S. average is 3,500 mg/day (3); in Australia, the average is 2,150 mg per day, but 34% get more than 2,300 mg (4). The U.K. Food Safety Authority estimates consumption in 2005 of 9,000 mg per day (4) and estimates in Europe are 3,100–4,600 mg/day (12). Brown and colleagues (13) concluded unfavorably high sodium intakes remain prevalent around the world. Sources of dietary sodium vary largely worldwide. If policies for salt reduction at the population level are to be effective, policy development and implementation need to target the main sources of dietary sodium in the various populations. In addition, it is important that strategies be found for reformulation and education. The challenges of salt and sodium reduction are multifold.

Sodium and Health: State of the Science Address

Sodium—The Basics

Sodium is an essential nutrient. It is required for the human body to function properly and achieve optimal health. The key electrolyte nutrients in the body are sodium, potassium, and chloride. These electrolytes are responsible for water balance and distribution. Additionally, osmotic equilibrium is directly impacted by the concentration of these electrolytes in the blood, leading to renal re-absorption of water and control of the volume of water in the blood. This in turn impacts blood pressure and other cardiovascular factors.

Not only are sodium and potassium critical for cardiovascular health, they are also key to establishing gradients across the cell wall membranes, creating electrical gradients which in turn are known as the Na+/K+ "pump." This electrical gradient or membrane action potential allows for muscle contractions and communication via nerves or neurons.

Blood Pressure

The relationship between sodium and blood pressure is a complicated physiological event involving multiple organs: lungs, heart, liver, kidneys; adrenal glands; and the blood arteries along with several enzymes and hormones (Fig. 3). The system known as the renin-angiotensin system (RAS) or the renin-angiotensin-aldosterone system (RAAS) is a hormone system that regulates blood pressure and water (fluid) balance. When blood volume is low, the kidneys secrete renin. Renin stimulates the production of angiotensin. Angiotensin causes blood vessels to constrict, resulting in increased blood pressure. Angiotensin also stimulates the secretion of the hormone aldosterone from the adrenal cortex. Aldosterone causes the tubules of the kidneys to increase the re-absorption of sodium and water into the blood. This increases the volume of fluid in the body, which also increases blood pressure. If the renin-angiotensin-aldosterone system is too active, blood pressure will be too high. There are many drugs that interrupt different steps in this system to lower blood pressure. These drugs are one of the main ways to control high blood pressure (hypertension [HTN]), heart failure, kidney failure, and harmful effects of diabetes (14,15).

The exact mechanism of HTN is not fully understood. The proposed mechanism is not exclusively driven by sodium intake alone, but by low potassium intake. Unfortunately, the modern western diet is high in sodium and low in potassium.

Table II. Sodium fast emerging as a top concern. Question: "Which of the following information, if any, do you use on the Nutrition Facts Panel?" Check all that apply.[a]

	2009 (%)	2010 (%)	Change (%)
Calories	75	74	–1
Sodium	56	63	+7
Total fat	69	62	–7
Sugars	61	62	+1
Saturated fat	56	52	–4
Serving size	54	52	–2
Trans fat	57	52	–5

[a]Source: 2010 (n = 698), 2009 (n = 763) IFIC Food & Health Surveys (9).

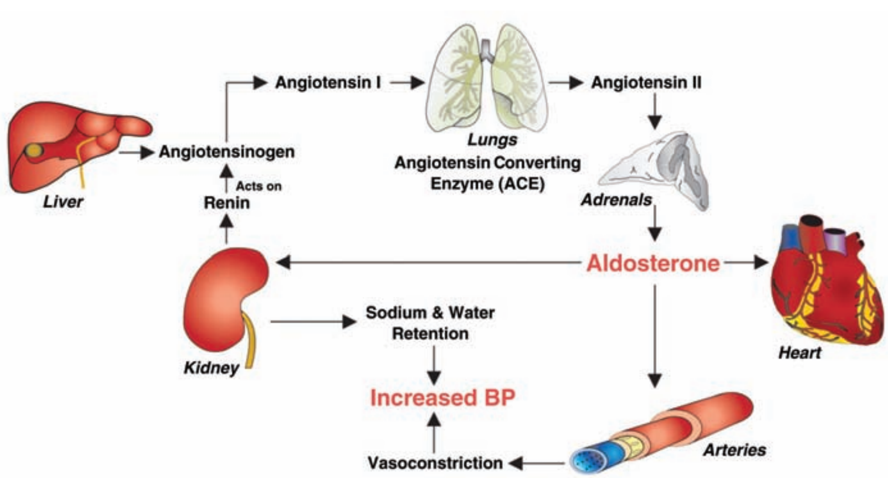

Fig. 3. Sodium physiology, blood pressure (14,15).

Along with a low potassium intake, there is poor conservation of potassium or retention which is evident by potassium loss in renal and fecal excretion. This loss or low level of potassium leads to greater retention of sodium by the renal pathway, leading to excess sodium in the body. At the cellular level, the excess sodium leads to extracellular fluid expansion which in turn causes greater deficit in potassium and HTN.

The consequences of chronic HTN left untreated can lead to stroke, blood vessel damage or arteriosclerosis, kidney failure, and heart attack or heart failure. So, although the focus generally ends up on heart health, the impact of sodium in the diet goes beyond.

Health Stats

Blood pressure is the pressure exerted by circulating blood on the walls of the blood vessels. During each heart beat, blood pressure varies between a maximum, systolic, and a minimum, diastolic, pressure. Table III shows the classifications of blood pressure for adults age 18 or greater. An average blood pressure of 112/64 mm of Hg is considered normal for the general population; however, various factors, including age, race, and gender impact typical blood pressure. As adults age, systolic pressure tends to rise and diastolic pressure tends to fall. According to data from the National Center for Health Statistics, the prevalence of HTN in U.S. adults has increased over the past 20 years from approximately 25% of the population in 1988-1994 to roughly 32% of the population in 2003–2006 (16). The impact of race is seen in that approximately 43% of the black population has HTN.

Facts About Hypertension

HTN is currently the leading cause of death, including myocardial infarction, stroke, congestive heart failure, and renal disease. More than 65 million, or one in three American adults, are affected by high blood pressure. About 28% of American adults ages 18 and older or about 59 million people have prehypertension, a condition that also increases the chance of heart disease and stroke. High blood pressure is especially common among African Americans who tend to develop it at an earlier age and more often than Whites. It is also common among older Americans. Individuals with normal blood pressure at age 55 have a 90% lifetime risk for developing high blood pressure. Blood pressure increases with age (17). Cardiovascular disease risk from HTN has no threshold; the systolic blood pressure is most important. The primary risk factors for HTN are family history; weight/obesity and a sedentary life; metabolic syndrome, such as diabetes; age; and ethnicity—it's more prevalent in African American and Hispanics. There is debate if diet is a primary risk factor. It is not clear if the dietary factor is excess sodium intake or low potassium, calcium, and magnesium intakes.

Dietary Intervention and Observations—Sodium

A review of dietary studies linking dietary sodium to cardiovascular disease outcome does not provide a "smoking gun." Studies can be sorted by outcome:

- Lower Salt Intake Associated with Cardiovascular Events
  - Worksite Hypertension Study (1995)
  - National Health and Nutrition Examination Survey (I, 1998; II, 2006; III, 2008)
- Salt Intake Had No Association with Cardiovascular Events
  - Honolulu Heart Study (1997)
  - Scottish Heart Health Study (1997)
  - Health Professional Study follow-up (1997)
  - Multiple Risk Factor Intervention Trial (2000)
  - Trials of Hypertension Prevention (1 and 2 follow-up mortality, 2007; Controls, 2009)
- Increased Salt Intake Associated with Cardiovascular Events
  - National Health and Nutrition Examination Survey, involving obese patients (2000)
  - Finnish Heart Study (2001)
  - Takayama (2005)
  - Trials of Hypertension Prevention 1 and 2, follow-up morbidity (2007)

The results do not lead to clear conclusions. Studies with lower and increased salt intake both can be associated with a cardiovascular event. Other studies show no association between salt intake and cardiovascular events. A review of select studies follows.

One approach is to look at specific subgroups based upon hypertensive disease state, race, gender, and age. This was done by Vollmer et al. when they examined the Dietary Approach to Stop Hypertension (DASH) diet. In all subgroups, the DASH diet and reduced sodium intake control diet were each associated with significant decreases in blood pressure; the two factors combined (sodium reduction and DASH diet) produced the greatest reductions. Among nonhypertensive participants who received the control diet, lower (vs. higher) sodium intake decreased blood pressure by 7.0/3.8 mm of Hg in those older than 45 years of age ($P < 0.001$) and by 3.7/1.5 mm of Hg in those 45 years of age or younger ($P < 0.05$) (18). This study indicates that sodium reduction may facilitate reduction in blood pressure. It is important to note that the DASH program also recommends consumption of a diet rich in potassium (4,700 mg/day), calcium (1,250 mg/day), and magnesium (500 mg/day), as well as protein and fiber. It also recommends a diet low in saturated fat, cholesterol, and total fat.

Another study that demonstrated blood pressure reduction was the Premier Trial. Randomized trial results suggest that among hypertensive patients or those with blood pressures in the high-normal range, lifestyle changes plus the DASH diet significantly lowered blood pressure compared with usual care (19). Subjects were able to successfully lose weight while lowering sodium, increasing fruit and vegetable intake, and modifying fat consumption. Note, mineral intake other than sodium was not monitored. A significant outcome was loss of weight in the study participants.

Sacks et al. also showed a direct relationship to sodium in the diet and blood pressure both when following the DASH diet and following a control diet (20). The effects of sodium were observed in participants with HTN and in those without HTN, blacks and those of other races, and women and men. The DASH diet was associated with a significantly lower systolic blood pressure at each sodium level; and the difference was greater with high sodium levels than with low ones. The reduction of sodium intake to levels below the current recommendation of 100 mmol per day and the DASH diet both lower blood pressure substantially, with greater effects in combination than singly. Long-term health benefits will depend on the ability of people to make long-lasting dietary changes and the increased availability of lower-sodium foods.

There is evidence to say that sodium consumption/excretion has remained constant over time and populations (21,22). In

Table III. Blood pressure classification

Classification	SBP (mm Hg)		DBP (mm Hg)
Normal	<120	and	<80
Pre-HTN	120–139	or	80–89
Stage 1 HTN	140–159	or	90–99
Stage 2 HTN	≥ 160	or	≥ 100

review of research on factors impacting HTN, several factors reputedly jump out—one is obesity. Research has shown that if obese, even following a lower sodium healthy diet, women remain at high risk for HTN (23). There are also studies that show that sodium is not the only important micronutrient in blood pressure moderation. Townsend et al. showed that low mineral intake is associated with high systolic blood pressure. Specific minerals monitored were sodium, potassium, calcium, and magnesium (24).

So, dietary sodium is important—but so are other minerals. What is of concern is that sodium intake is high and potassium intake low. See Figure 4 for the level of sodium and potassium in the diet by age group. Note, the recommended level of potassium intake is 4,700 mg per day—the dashed line at the top. The current daily dietary guideline for sodium is 2,300 mg per day. The USDA Dietary Guideline Advisory Committee is considering a recommendation in the 2010 Dietary Guidelines at a reduced level of 1,500 mg per day, also shown on the graph. Overall, males are consuming more sodium and potassium than females (25).

Many foods contribute to the high intake of sodium. While some foods are extremely high in sodium, the problem of excess sodium reflects frequent consumption of foods that are only moderately high in sodium. As shown in Figure 5, in 2005–2006, the major sources of sodium intake among the U.S. population were yeast breads; chicken and chicken mixed dishes; pizza; pasta and pasta dishes; cold cuts; condiments; Mexican mixed dishes; sausage, franks, bacon, and ribs; regular cheese; grain-based desserts; soups; and beef and beef mixed dishes. Each of these 12 food groups supplies more than 100 mg of sodium per person per day to the diet. Collectively, this group of foods contributes about 56% of the dietary sodium, or nearly 2,000 mg per person per day in just these foods. Figure 5 shows the sodium contribution of these 12 food groups as well as the smaller contributions of other foods. It clearly shows numerous foods contribute to the high intake of sodium of Americans (25).

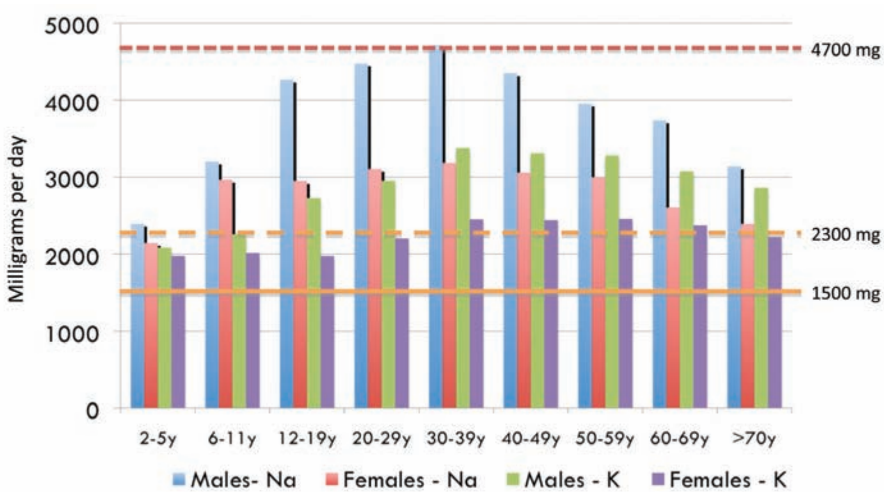

Fig. 4. Estimated mean daily sodium (N) and potassium (K) intakes by age/sex group, 2005–2006 (25).

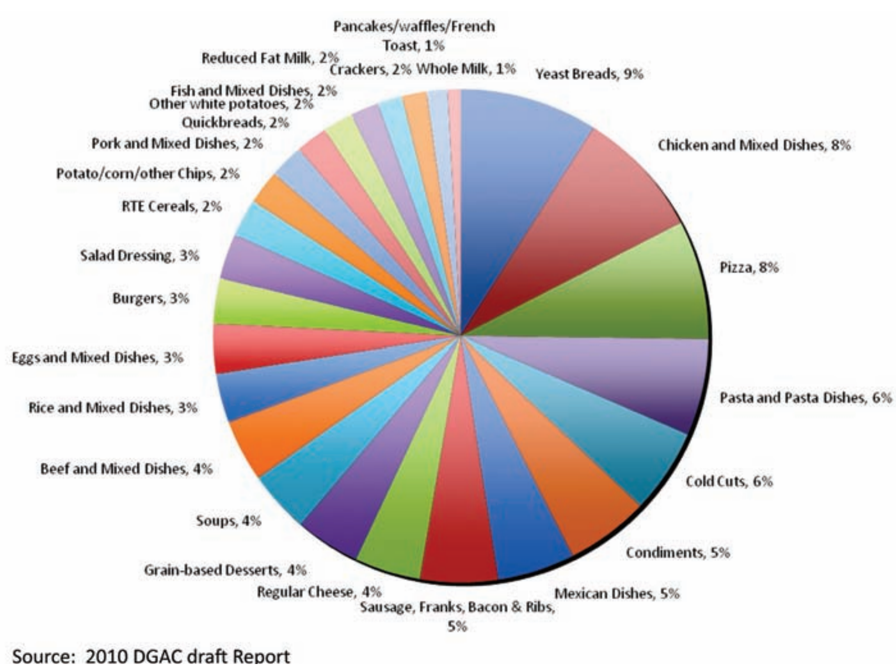

Fig. 5. Sources of sodium in the diet (25).

The 2010 Dietary Guidelines Advisory Committee (DGAC) has provided the following major conclusions in regard to sodium:

- Major Conclusions
  - A strong body of evidence has documented that in adults, as sodium intake decreases, so does blood pressure.
  - A moderate body of evidence has documented that as sodium intake decreases, so does blood pressure in children, birth to 18 years of age.
  - The projected health benefits of a reduced sodium intake are substantial and include fewer strokes, cardiovascular disease events, and deaths, as well as substantially reduced health care costs.
  - Children and adults should lower their sodium intake as much as possible by consuming fewer processed foods that are high in sodium, and by using little or no salt when preparing or eating foods.

Based on those conclusions the DGAC has made the following recommendations:

- Recommendations
  - In 2005, the DGAC recommended a daily sodium intake of less than 2,300 mg for the general adult population and stated that hypertensive individuals, Blacks, and middle-aged and older adults would benefit from reducing their sodium intake even further.
  - Because these latter groups together now comprise nearly 70% of U.S. adults, the goal should be 1,500 mg per day for the general population.
  - The reduction from 2,300 to 1,500 mg per day should occur gradually over time.
  - Both children and adults should reduce their sodium intake.
  - Individuals should also increase their consumption of dietary potassium because increased potassium intakes helps to attenuate the effects of sodium on blood pressure.

When trying to understand HTN and its relationship to sodium in the diet, one must consider that HTN is complex with many causes and risk factors, including genetics, race, gender, and environmental factors. The environmental factors include inactivity, stress, obesity, tobacco, age, alcohol, sodium, potassium, and intake of other minerals.

If we are looking for ways to cure the health of the general population, there is evidence to say that greater health benefits and cost reduction can be realized with caloric reduction leading to weight loss than can be realized with reduction in sodium (25). Figure 6 compares the potential annual savings in medical costs related to lowering sodium versus fat or calories (26). Individuals respond differently when it comes to impacts on blood pressure. Factors affecting blood pressure reduction are heterogeneous. Sodium restrictions' impact on blood pressure regulation is not uniform across the adult population. There are some individuals who are known to be "salt sensitive." These are the individuals with the greatest reductions in blood pressure in response to decreased sodium intake. No diagnostic test exists to identify these individuals, therefore it is impossible to classify individuals as salt sensitive or not. Sodium sensitivity is modifiable. If someone is sodium sensitive, the impact can be attenuated by potassium and the DASH diet. Lifestyle modifications can lead to blood pressure reduction, but there is more than just sodium reduction for consideration. Weight reduction, DASH diet, sodium reduction, physical activity, and limiting alcohol consumption all contribute to reduction in HTN.

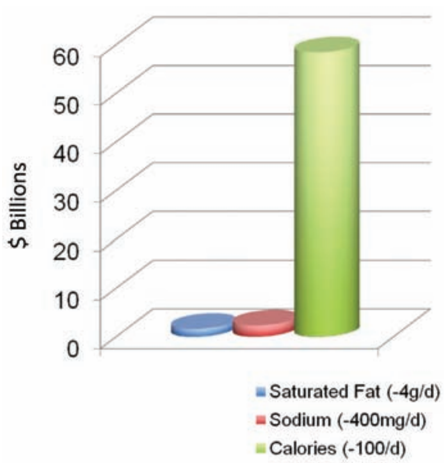

Fig. 6. Healthcare savings may be greater with caloric reduction (weight loss) than sodium reduction. Potential annual medical savings by reducing daily saturated fat, sodium, or calories (26).

There is a need for ongoing research to further understand environmental factors and their impact on blood pressure/ HTN. Some needs include a) conducting studies, including clinical trials, on children to determine the effects of sodium on blood pressure and the age-related rise in blood pressure; b) conducting trials that determine the effects of sodium reduction on clinically relevant non-blood pressure variables, such as left ventricular mass, proteinuria, and bone mineral density; c) conducting controlled trials that test whether increased potassium intake through supplements or potassium-rich foods increase bone mineral density; and d) conducting dose-response trials that test the main and interactive effects of sodium and potassium intake, as well as the possible impact of other minerals (e.g., calcium, magnesium) on blood pressure and other clinically relevant outcomes.

Sodium is essential for life. Most people are at risk for developing HTN over their lifetime. Excess sodium intakes are linked to elevated blood pressure. Sodium intakes are well in excess of adequate intake level in most countries. Minerals, potassium, calcium, and magnesium are low in intake and may contribute to elevated blood pressure because they are too low, and or may attenuate the effects of sodium on blood pressure if consumed at recommended levels. There are gaps in the available research. And ultimately—the pathophysiology of HTN is multifactorial—multiple lifestyle modifications can reduce blood pressure better than sodium reduction alone.

Perhaps public policy is on the verge of outpacing consensus science. Sodium effects on health are hotly debated. Scientific evidence is limited in many ways: methodological limitations, limited evidence linked directly to mortality, no published data to support survival advantages of low-sodium intakes, and safety of low-sodium intakes has not been assessed adequately. Nonetheless, it appears that the food industry faces a crux of required change—sodium reduction is being promoted as a tool to improve health and increase safe food consumption. So, what can we expect in regard to regulation and legislation?

Regulating Dietary Sodium to Promote Public Health: The Global Policy Landscape and Outlook

The question of how best to employ laws and regulations to advance diet-related public health goals is one which is not readily answered by simple or speedy strategies. This question appears to present distinctive challenges in the context of strategies to reduce the risk of HTN by reducing dietary sodium intake in the U.S. population. The 2005 Dietary Guidelines for Americans recommends that sodium intake be kept below 2,300 mg per day to promote healthy blood pressure levels, and the 2010 DGAC recently recommended that sodium intake be further limited to levels not to exceed 1,500 mg/day (27).

According to a study issued by the Institute of Medicine (IOM) in 2010 entitled "Strategies to reduce sodium intake in the United States," despite good intentions and solid commitments of policymakers and stakeholders, U.S. policies aimed at reducing sodium intake during the past 40 years through voluntary measures have failed, and the time has come for a shift toward more aggressive mandatory regulatory policies to reduce sodium intake and related HTN and cardiovascular disease risks (28). The IOM study reviews a wide variety of NHANES and other public health data, and concludes that sodium intake in the U.S. population currently exceeds recommended levels and the prevalence of excessive sodium intake puts the whole population at significant risk for HTN and related cardiovascular disease, including heart failure and stroke. For example, the IOM study observes that approximately 32% of U.S. adults already have HTN, and another 33% of adults have elevated blood pressures that qualify as "pre-hypertension." As a result, the overall percentage of U.S. adults affected by unhealthy blood pressure levels exceeds 60%. The IOM study further observes that unhealthy blood pressure levels have serious adverse economic consequences for the nation, citing data suggesting that the costs associated with HTN amounted to $73.4 billion in 2009 alone.

Based on NHANES 2003–2006 data, the IOM report concludes that about 88% of Americans age 2 years and older have "excessive" dietary sodium intake levels which exceed the "tolerable upper intake level" (UL) for sodium. These data show that excessive sodium intake levels are even more prevalent among children and youth, with 93% of 4–8 year olds and 94% of 9–13 year olds consuming sodium at levels exceeding the UL (Fig. 7). In addition, the IOM study cites NHANES data indicating that a wide variety of foods and food ingredients contribute to dietary sodium intake levels, including grain foods which account for 11% of dietary sodium intake. Among grain foods, the five leading contributors to overall dietary sodium intake are bread, cold cereal, rice, breakfast breads (e.g., pancakes, waffles, etc.), and crackers. The IOM study evaluates data concerning the relatively low levels of sodium that naturally occur in grains, and concludes that the significant contribution grain foods make to overall dietary sodium intake levels is attributable largely to added ingredients, such as sodium-containing leavening agents, emulsifiers, and salt.

The IOM study questions the adequacy of the Nutritional Labeling and Education Act (NLEA) legal framework and existing FDA implementation of regulations for achieving the significant reductions in sodium intake that IOM considers to be necessary to reduce the prevalence of HTN and related cardiovascular disease risk to acceptable levels. The NLEA framework was designed to equip consumers with information concerning sodium and other nutrient levels in food enabling consumers to choose lower sodium foods as part of an overall healthy diet through a system of "carrot" and "stick" incentives implemented through food labeling regulatory requirements. Under the NLEA framework, essentially the "carrot" amounts to policies that allow manufacturers to voluntarily promote their lower sodium foods with such nutrient content claims as "reduced sodium," "low sodium," and "very low sodium." The "stick" amounts to mandatory nutrition labeling requirements that apply to all foods and require sodium levels to be disclosed on a per serving basis, allowing consumers to compare foods based on sodium and other nutrient levels. The IOM study cites evidence suggesting that the carrot and stick incentive structure established by the NLEA framework has not provided adequate incentives to encourage food manufacturers to develop and market reduced-sodium foods, and has not enabled consumers to shift their dietary practices in ways that reduce overall dietary sodium intake levels. The IOM study cites data showing that annual per capita salt disappearance has increased since the NLEA regulatory policies were implemented, and that the number of new food products promoted with "reduced" and "low" sodium content claims has actually declined significantly during the period since the NLEA was implemented (Fig. 8). The IOM study recognizes that sodium-related taste preferences are acquired, and that foods that are labeled as "reduced-" or "low-" sodium foods may have little appeal for consumers acclimated to saltier tasting foods.

Ultimately, based on its review of public health data concerning sodium intake and HTN prevalence and the implications of the NLEA and related regulatory policies, the IOM study concludes that the U.S. experience over the past 40 years casts doubt on any future strategy that is purely voluntary, and advocates the adoption of a more aggressive and compulsory regulatory model to gradually reduce sodium levels in the food supply in a manner that will allow consumer taste preferences to adjust and will deliver the health benefits of a lower sodium diet to consumers passively, and not only to those who are able to actively choose to adopt and maintain lower sodium dietary practices through individual food choices. The IOM reports highlights the gains to public health that have been achieved through comparably passive food regulatory strategies requiring certain foods, including grain foods, to be fortified with essential nutrients and which rapidly reduced the risk of such diseases as beri beri, pellagra, and neural tube defects. The IOM study concludes that the time has come for the United States to adopt as its primary strategy for reducing sodium intake in the U.S. population, FDA regulations which limit the amount of salt- and sodium-containing ingredients that manufacturers can add to food rather than relying principally on food labeling and consumer education strategies to encourage consumers to make the changes in behavior that would be necessary to reduce sodium intake to recommended levels. IOM recommends that FDA promulgate regulations to limit the amount of salt and other sodium-containing ingredients in food based on the agency's existing authority to affirm the conditions under which the use of a food ingredient is GRAS and related authority to require ingredients that are not determined to be GRAS to be approved by FDA as food additives before they can be used in foods for human consumption, including in meat, poultry, and egg products subject to regulation by USDA's Food Safety and Inspection Service (29). More specifically, the IOM study recommends that FDA issue regulations prescribing the conditions under which FDA has determined the use of salt and other sodium-containing ingredients to be GRAS, and thus excluded from the premarket approval requirements that apply to food additives under the Food, Drug, and Cosmetic Act (FDCA). IOM further recommends that FDA implement the new regulatory program in a manner that gradually ratchets sodium levels in the food supply down-

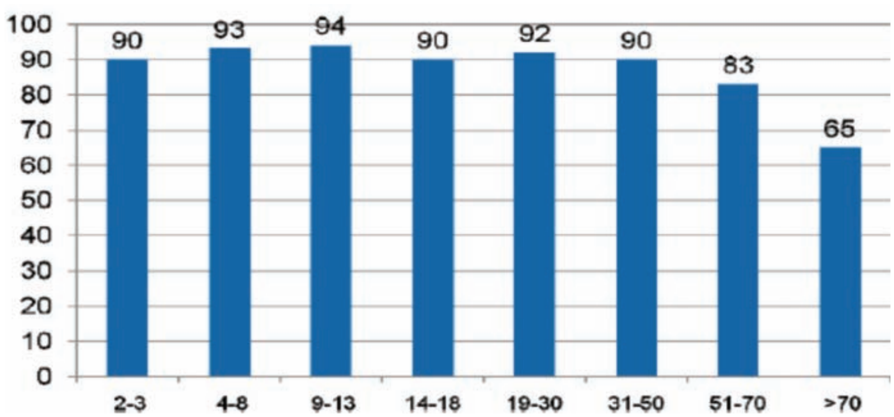

Fig. 7. IOM Sodium Report findings: For 88% of Americans, sodium intake is too high. Percentage of persons 2 years of age or more exceeding the tolerable upper intake level (UL) for sodium from foods (28).

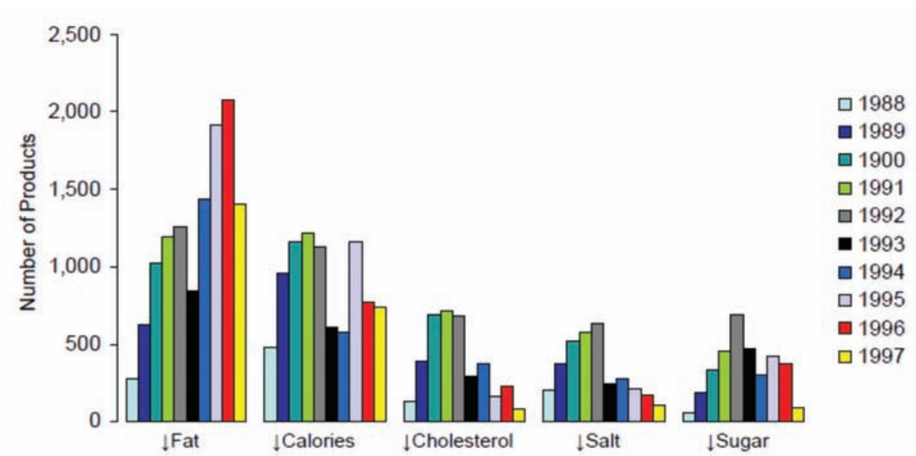

Fig. 8. IOM Sodium Study: Post-NLEA, reduced and low claims have declined. Number of new food products bearing nutrient claims, 1988–1997. Note: the ↓ indicates "reduced" or "low" for fat, calories, salt, and sugar, and "low" or "no" for cholesterol (28).

ward toward the target levels gradually over time, and is accompanied by an evaluation program to monitor program effectiveness throughout the implementation period. The IOM study also recommends that the purchasing power of federally funded programs be used to provide incentives for the development of reduced-sodium foods (e.g., establish sodium content specifications for foods purchased by the Department of Defense, or made available through the USDA feeding programs [e.g., WIC, school lunch, etc.]).

While the IOM study makes concrete recommendations which advocate for the establishment of mandatory sodium-reduction regulatory policies based on existing provisions of the FDCA and other statutes, the IOM recommendations are confined to legal and regulatory concepts and do not attempt to provide a detailed roadmap concerning precisely how the recommended salt/sodium limits should be implemented with respect to grain products or other specific categories of food, or with respect to "salt" or other specific sodium-containing ingredients (e.g., leavening agents, emulsifiers, preservatives, other). On the other hand, the IOM study includes a detailed review of the sodium-reduction strategies that have been adopted in Finland, the United Kingdom, Ireland, France, the European Union, and Canada, and the sodium-reduction strategies emerging globally may inform the U.S. policy development process going forward (30).

Finland is the only country that has implemented a sodium-reduction policy that is considered to be "mandatory." Finland adopted its mandatory policy in 1993 after implementing a range of public health intervention programs aimed at increasing public awareness concerning the relationship between sodium intake and HTN risk during the previous 20-year period, including through public service announcements and media campaigns launched during the 1970s and 1980s. In 1993, Finland adopted a more aggressive sodium-reduction strategy which established mandatory labeling requirements for food products, including a mandatory statement disclosing the "percent salt" by weight, and requiring foods containing salt and levels exceeding prescribed thresholds to bear a "high salt" label. For example, under the mandatory labeling system, bread containing more than 1.3% salt by (fresh) weight must be labeled as a "high salt" food. Breakfast cereal containing more that 1.7% salt by weight must be labeled as a "high salt" food. In conjunction with the mandatory labeling requirements, the Finnish government implemented an evaluation program designed to periodically monitor sodium intake and blood pressure levels in the population every five years. The IOM study cites data from the monitoring program in Finland suggesting that average sodium intake may have dropped as much as 1,000 mg per day in the population, and that significant reduction in blood pressure and the rates of HTN and stroke may also have occurred since the labeling program was implemented. In addition, the evidence suggests that manufacturers have reformulated and discontinued products in order to avoid labeling requirements for "high salt" food products.

Currently, the most comprehensive such "voluntary" program is being implemented in the United Kingdom, and employs a three-prong strategy consisting of a) programs designed to encourage the food industry to reformulate products to reduce sodium levels on a voluntary basis, b) a public relations campaign aimed at increasing public awareness concerning the relationship between sodium intake and HTN risk and ways to reduce sodium intake, and c) "voluntary" front-of-package "traffic light" labeling, which employs a color-coded signaling system to inform consumers whether the sodium levels in food are deemed to be "high" (red), "medium" (amber), or "low" (green) by public health officials. The color coding system is designed to ratchet down the levels in the food supply over time by reducing the target levels of salt/sodium deemed to be "high," "medium," and "low." The United Kingdom has issued target levels for 2012 which are lower than those established for 2010, for example. Under the current target levels, bread containing more than 1,500 mg of sodium per 100 g would qualify for a "red" traffic signal, bread containing more than 300 mg and up to 1,500 mg of sodium per 100 g would qualify for an "amber" signal, and bread containing 300 mg or less per 100 g would qualify for a "green" traffic signal. The IOM study cites preliminary evidence from a study of a random sample of 700 people in the United Kingdom which suggests that sodium intake may have declined as much as 400 mg per day since the program was started, based on urinary sodium levels.

For the most part, the sodium-reduction strategies being implemented internationally focus on the creation of various kinds of commercial incentives to encourage food manufacturers to reduce the amount of salt and sodium that is added to food on a voluntary basis, combined with public health education programs aimed at encouraging consumers to modify their dietary practices to reduce sodium intake. While the programs that have been adopted in Finland and the United Kingdom are likely to inform policy developments in the United States, in view of the significant differences in the populations and sodium intake patterns of the U.S. population some caution must be exercised in determining what lessons can be drawn from these and other international regulatory models for reducing dietary sodium intake as a strategy for reducing HTN and related cardiovascular disease prevalence in the United States.

The challenge of sodium reduction is now a higher priority as food and beverage formulators anticipate potential government and regulator intervention. There are key functionalities that are known in regard to salt and sodium in formulations. Grain-based products and baked goods are being targeted for reduction in sodium because of their current level of sodium and their contribution to overall sodium in the diet. Efforts are underway to understand more fully the impact of sodium on two key aspects, sensory and bake performance.

Sodium Functionality in Bakery Applications, Sensory Aspects, and Interaction with Constituents[1, 2]

A study is being conducted by the German Research Center for Food Chemistry and the Technical University of Munich with the objectives to study the effects of sodium reduction on dough and bread properties; study the interaction between sodium ions and the components of wheat flour (i.e., proteins, starch, lipids) by studying the extractability of sodium ions from bread crumb during mastication as a basis for the salt reduction in wheat bread; studies on the relationship between sodium chloride concentration and sensory properties of wheat bread sodium chloride on the flavor of bread; and identification of methods allowing the reduction of sodium chloride in bread while maintaining taste and breadmaking properties.

When examined via confocal laser scanning microscopy, wheat dough shows less

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interconnected protein when sodium chloride is not present. As sodium chloride concentration increases, there is formation of a protein network. It appears that sodium chloride neutralizes the electrostatic repulsion of gluten particles, leading to improved aggregation of the gluten protein. The consequence is increased mixing time. Resistance of the dough is also increased while there is an ideal level of salt related to extensibility peak. Not only is the dough impacted, but the baked good also is impacted by salt level. Maximal bread volume is at 0.5 g of salt per 100 g of flour. Decrease in loaf volume occurs at high salt concentrations, greater than 2 g of salt per 100 g of flour. Crumb firmness increases in particular with salt amounts greater than 2 g per 100 g of flour. Lower water activity leads to an increased rate of bread staling. Osmotic effect lowers yeast activity leading to less and smaller crumb pores as well as an increased initial crumb firmness.

Sensory Studies

All sensory studies were conducted by a trained sensory panel. The influence of sodium chloride on the flavor of bread was investigated by compiling flavor profiles of wheat bread containing 0, 0.7, 1.5, and 2% sodium chloride. Minimum detectable differences in salt concentration in wheat bread as well as detection and salt recognition thresholds for sodium chloride in bread crumb and in water extracts of bread crumb (1 g crumb/2.5 ml water, extraction by Ultra-Turrax) were determined by means of duo-tests. Sodium concentrations in the water extracts were measured by ion chromatography (IC).

Sodium Binding by Bread Constituents

Sodium extractability from wheat bread was investigated by extracting bread crumb containing 0–6% sodium chloride (based on flour) with 2.5 ml ultrapure water per g crumb, with buffer solutions (pH 7 and 9) and with artificial saliva (with and without α-amylase) for 1 minute at 37°C using a modified Potter S Homogenisator (Braun, Melsungen) as a model mouth. The effects of different mastication times ranging from 15 seconds up to 15 minutes were examined. After centrifugation, the sodium concentrations of the supernatants were determined by atomic absorption spectrometry (AAS), by IC, and by an ion-selective electrode (ISE). The total sodium concentration in bread crumb was measured by AAS and by inductively coupled plasma optical emission spectrometry (ICP-OES) after nitric acid/hydrogen peroxide digestion.

Binding of sodium to protein fractions isolated from wheat flour was measured by means of two methods. Sodium binding to water-soluble albumins was determined by a magnetic beads-based assay, where binding of sodium to other wheat protein fractions obtained after a modified Osborne fractionation (combined albumin/globulin fraction, gliadins, glutenins) was determined by incubating the proteins with buffered solutions of sodium chloride, removal of insoluble material by centrifugation, and measurement of the sodium concentration in the supernatant by ISE.

Results and Discussion

The flavor profiles of wheat breads containing 0–2% salt showed the influence of sodium chloride not only on the saltiness but also on the whole flavor of wheat bread; increasing contents of sodium chloride led to a decrease of yeast-like, musty, and floury/watery flavor attributes (Fig. 9).

The minimum detectable difference in the salt concentration of wheat bread strongly depended on the absolute level. When bread without salt was used as the control, the minimum detectable difference was as low as 0.075%. However, when bread containing 1% sodium chloride was used as a reference, the minimum detectable difference in the salt concentration increased to 0.3%.

Detection and salt recognition thresholds determined for sodium chloride in bread crumb and in water extracts of bread crumb are presented in Table IV. Considering the standard deviations, the threshold values in bread crumb were comparable to the salt concentrations in bread corresponding to the threshold values in the water extracts of bread crumb. The salt recognition threshold in an aqueous bread extract was higher than in pure water (31). Thus, in this concentration range perception of saltiness seemed to be influenced by further substances extracted from bread crumb.

In order to determine the extractability of sodium from bread crumb, the total sodium concentrations in the crumb of the different breads were determined by AAS and ICP after acidic digestion. These results corresponded to the sodium concentrations obtained by formula-based calculation (Fig. 10). The sodium concentrations in the extracts obtained after "chewing" with ultrapure water in the mastication simulator were determined by AAS, IC, and ISE. Considering the standard deviations, these methods showed identical results and revealed that the total amount of sodium present in the bread crumb had been extracted by "chewing" (Fig. 10).

Variation of the chewing liquid gave comparable results. The entire amount of sodium was extracted from the crumb when ultrapure water was replaced by buffer solutions (pH 7 and 9) and by artificial saliva (with and without αamylase). A mastication time of only 15 seconds was sufficient to completely extract sodium from the bread crumb (data not shown). Hence, saltiness of bread doesn't seem to be affected by incomplete extractability of sodium from the crumb. This means that interactions between sodium ions and the constituents of wheat bread are sufficiently weak to enable complete sodium extraction already after a very short mastication time.

Quantitative determination of sodium binding to wheat proteins was done by a

Table IV. Threshold values for sodium chloride in bread crumb, in water extracts of bread crumb and in water

Bread crumb	
Detection threshold	0.08 ± 0.06% NaCl
Salt recognition threshold	0.16 ± 0.08% NaCl
Water extracts of bread crumb (1 g crumb/2.5 mL)	
Detection threshold	0.34 ± 0.26 g NaCl/L (= bread with 0.16 ± 0.12% NaCl)
Salt recognition threshold	0.59 ± 0.30 g NaCl/L (= bread with 0.28 ± 0.14% NaCl)
Water	
Salt recognition threshold	0.21 g NaCl/L[a]

[a]See Schiffman et al. (31).

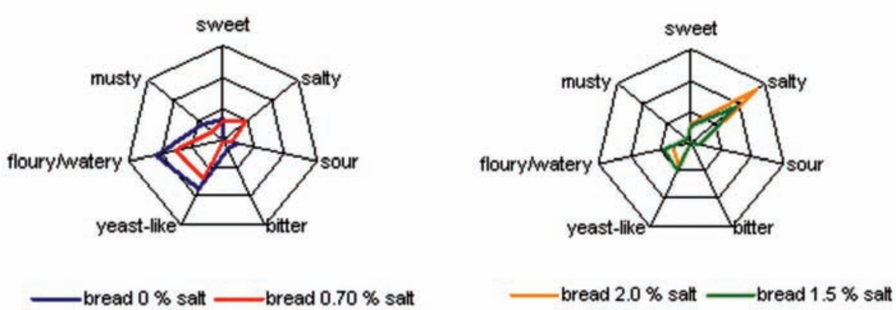

Fig. 9. Flavor profiles of wheat breads containing 0, 0.7, 1.5, and 2.0% salt.

magnetic beads assay and by ISE measurements. At pH 9, higher amounts of sodium were bound to each fraction of the wheat proteins than at pH 7 (Fig. 11). These results indicated that ionic interactions to amino acids with negatively charged side chains are involved in the binding of sodium ions. However, our results indicate that the sodium ions of only less than 0.01% of sodium chloride in wheat bread (based on flour) were able to be bound by wheat proteins. Concerning the minimum detectable difference of 0.3% of sodium chloride in bread with conventional sodium concentrations, binding of sodium to wheat proteins can be considered to be negligible with regard to the perception of saltiness. Nevertheless, the salt recognition threshold in an aqueous bread extract was higher than in pure water. Therefore, we think that saltiness might overlap with other flavor components, and further studies will elucidate the effects of viscosity and texture on the mobility of sodium ions.

Conclusion

Overall, in regard to dough and baked product performance, salt appears to increase the osmotic pressure leading to a reduction in yeast activity and a decrease in the crumb pore size. Dough strengthening effect of salt by partial reduction of electrostatic repulsion between gluten molecules and increased aggregation of gluten molecules delivered smaller and more regular crumb pores, thereby increasing crumb firmness. Salt also increased the mixing time and dough resistance. A maximum loaf volume was achieved at 0.5% salt.

Sensory considerations show that sodium chloride affects the overall flavor profile of wheat bread. Sodium recognition strongly depends on salt content. Sodium is completely extracted from bread crumb in the chewing simulator. Binding of sodium to the isolated protein fractions is negligible for the perception of saltiness in wheat bread; nevertheless, the salt recognition threshold in an aqueous bread extract is almost three times as high as in pure water. It may be that other flavor components overlap with saltiness in the bread or that mobility of sodium ions is affected by viscosity or texture.

Bread is one of many baked goods—and when considering sodium content and source, perhaps one of the more simplified systems, as the primary if not only source of sodium is salt. Other baked goods and food products are more complex. Identification of strategies to replace the key sensory attributes associated with salt and sodium while maintaining functionality is critical to delivering consumers a reduced- or low-sodium food or beverage.

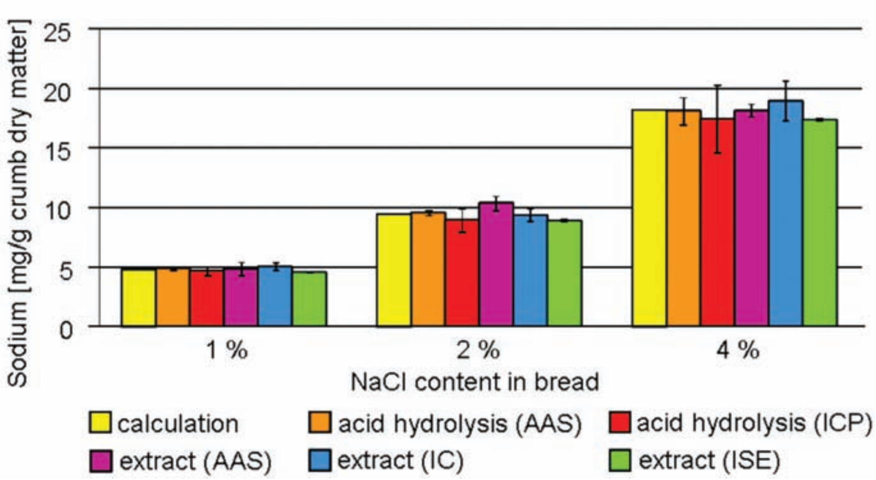

Fig. 10. Concentration of sodium in bread crumb determined after acid hydrolysis (measured by atomic absorption spectrometry [AAS] and inductively coupled plasma mass spectrometry [ICP]), in comparison to its extractability in the mastication simulator (measured by AAS, ion chromatography [IC] and ion selective electrode [ISE]) and to the values obtained by formula-based calculation.

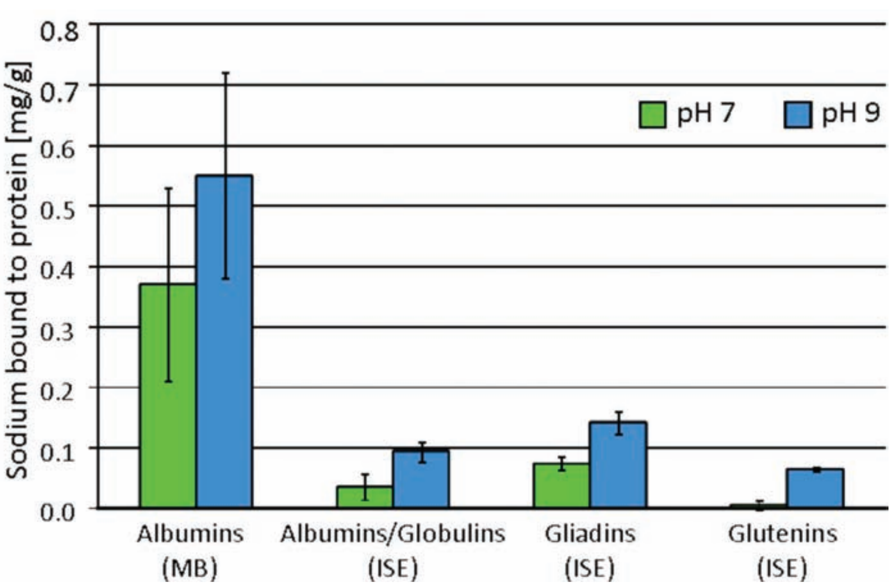

Fig. 11. Binding of sodium to wheat proteins as determined by a magnetic beads assay (MB) and by ion selective electrode (ISE).

Challenges and Strategies for Sodium Chloride Reduction

Sodium chloride is a multifunctional ingredient which makes it very difficult to reduce and replace. It provides a uniquely salty taste to food because nothing else tastes like sodium chloride. In addition, it is a very effective bitter masker and overall flavor enhancer. Salt also functions in many ways beyond taste. It improves the texture of products by providing mouthfeel and structure to food. For example, it aids in gluten development of baked goods. It also enhances the color of baked goods by aiding the Maillard browning reaction. Preservation is another important function because sodium chloride is a very effective inhibitor of pathogen growth.

Whether you're working in a "wet" system such as a sauce, a "dry" system such as dough used to make bread and expanded cereals, or a topical application to salty snacks, the same hurdles to sodium reduction exist. Safety, quality, function, and cost must all be taken into consideration. Anyone who has worked on sodium reduction knows it's not an easy task because there is no single solution to reducing sodium content. The best success is achieved when leveraging multiple tools based on a wide range of technologies. Unfortunately, the combinations of tools that work in one system, such as a sauce, don't work in another, such as expanded cereal. Usually, further adjustments to the total taste solution are needed for each flavor in a product line.

There are tools available to get a sodium-reduction program started but first it's important to complete a holistic program review. Begin by defining your sodium-reduction target. What are your cost targets? Do you need to consider Kosher labeling? Setting clear expectations before you begin can greatly facilitate your ability to reach your goal. It is also important to identify the sources of sodium before beginning any reduction work. Look for the hidden sources of sodium. Ingredients such as chemical leaveners, emulsifiers, and stabilizers can add sodium to your product and it can make this challenge easier if you understand all the sources. Table V provides a list of common sodium-containing compounds and their function in foods. Understanding the sources of sodium can guide your sodium-reduction strategy (28). You will need to determine where to start. Is it with the biggest contributor on the list? One must consider what source(s) might be easier to remove or replace.

There are three main approaches for sodium chloride reduction: reduce, replace, and enhance. Reducing the amount of salt is the best place to start. However, it's important to understand the implication of sodium chloride reduction on food safety. Maintaining overall product quality and safety overrides simple reductions. Sodium chloride reduction is also possible by changing the morphology of the salt crystal. Most common technical approaches are reducing the granulation size and changing its shape. These approaches work best where rapid solubility is important for flavor or function such as topical applications. It doesn't work as well where complete solubilization occurs during processing or shelf life.

Replacement of sodium chloride is the next best method to reducing salt in a product. Cations similar to sodium such as potassium work best. However, a bitter or metallic off-flavor is often sensed when potassium chloride is used. Other mineral salts can partially replace salt in a cost-effective manner as well, but, they often deliver off-flavors which can limit their use. In addition, other mineral salts do not function the same and require other tools to manage preservation, texture, and color. Typical mineral salts include sea salt, potassium chloride, magnesium chloride, calcium chloride, potassium lactate, and magnesium sulfate. One key to success is to balance non-sodium salt levels from all sources to minimize off-flavors. The increased use of mineral salts has accelerated the search for bitter maskers. Sweeteners are commonly used for this function.

A number of other tools exist for enhancing salt taste and overall flavor. These include: reaction flavors, autolyzed yeast extract, ribonucleotides, amino acids, and organic acids. These tools are specific to each product system and their flavor intensities can be strong so they may have limited use in milder flavored products.

Other ingredients such as chemical leaveners also contribute to the sodium level, and are the second greatest contributors of sodium after sodium chloride. The chemical leavening system consists of two components, the source of carbon dioxide, generally sodium bicarbonate, and acid salts used to neutralize the bicarbonate to release carbon dioxide at controlled rate and time. For the bicarbonate, the current option for sodium reduction is to use potassium bicarbonate instead of sodium. For the leavening acid salts, there are potassium and calcium phosphate options as well as low-sodium options, including calcium ortho-phosphates (monocalcium and dicalcium phosphate), calcium acid pyrophosphates (CAPP) with varying rates of reaction, and potassium or sodium aluminum phosphates. In the case of these ingredients, the degree of formulation substitution is end-product specific based on taste and functionality.

Overall, salt reduction while maintaining the quality of your product is not easy. Be sure you understand your system and its sources of sodium, then build your strategy. Often following the three main approaches of reduce, replace, and enhance can deliver the most successful outcome.

Given the challenges and tools that currently exist, it is important to also look at new technologies and processes that are in development.

Table V. Common sodium-containing compounds and their functions in food

Emulsifying Agents
Sodium pyrophosphate
Dioctyl sodium sulfosuccinate
Disodium hydrogen phosphate
Sodium alginate
Sodium caseinate
Sodium phosphate
Trisodium citrate
Trisodium phosphate
Sodium stearoyl lactylate

Buffering Agents
Aluminum sodium sulfate
Disodium hydrogen phosphate
Sodium adipate
Sodium dihydrogen citrate
Sodium dihydrogen phosphate
Sodium DL-malate
Sodium hydrogen carbonate
Sodium phosphate
Trisodium citrate
Trisodium phosphate

Anticaking Agents
Sodium aluminosilicate
Sodium ferrocyanide

Flavor-Enhancing Agents
Monosodium glutamate
Disodium 5'-guanylate
Disodium 5'-inosinate
Disodium 5'-ribonucleotides

Leavening Agents
Sodium bicarbonate
Disodium pyrophosphate
Sodium acid pyrophosphate
Sodium aluminium phosphate
Sodium hydrogen carbonate

Dough-Conditioning Agents
Sodium stearoyl lactylate
Sodium stearoyl fumarate

Stabilizing Agents
Disodium ethylenediaminetetraacetic acid (EDTA)
Disodium pyrophosphate
Potassium sodium L-tartrate
Sodium alginate
Sodium carboxymethylcellulose
Sodium caseinate
Trisodium citrate
Sodium stearoyl lactylate

Neutralizing Agents
Trisodium phosphate
Sodium sesquicarbonate
Sodium phosphate
Sodium DL-malate
Sodium dihydrogen phosphate
Sodium dihydrogen citrate
Sodium citrate
Sodium adipate
Aluminum sodium sulfate
Sodium potassium tartrate
Sodium acetate

Thickening Agents
Sodium alginate
Sodium carboxymethylcellulose

Moisture-Retaining Agents
Sodium hydrogen DL-malate
Sodium lactate
Sodium lauryl sulfate

Texture-Modifying Agents
Sorbitol sodium
Sodium tripolyphosphate
Pentasodium triphosphate
Disodium hydrogen phosphate

Bleaching Agent
Sodium metabisulfite

Developing Strategies for Improving the Sensory Profile of Sodium-Reduced Foods

The need for salt reduction is clear to consumers, dieticians, and food manufacturers. As bread and cereal products account for ~25-35% of the dietary sodium intake (32), substantial sodium reductions in these products are demanded. But how do we realize a substantial reduction of sodium intake, whilst maintaining high-quality food and consumer acceptance? The complexity of this issue requires innovative approaches. Existing and new strategies are used by TNO to improve the sensory profile of sodium-reduced bakery products.

The Complexity of Sodium Reduction in (Bakery) Products

It is difficult to lower the sodium content of bakery products, since sodium fulfills various important functions in these products. First, NaCl plays an important role in the breadmaking process, because it regulates the fermentation rate and strengthens the gluten. Secondly, NaCl is a very effective preservative. Hence sodium reduction may affect the shelf-life and safety of products. Finally, NaCl contributes largely to the highly desired salty taste of bread and also enhances the overall flavor of bread. This taste functionality of NaCl is particularly difficult to replace. So, the three key target challenges to sodium reduction are maintaining bake performance, preservation characteristics, and flavor.

Sodium Reduction while Maintaining Processing and Product Quality

As sodium concentration has a strengthening effect on gluten, sodium reduction decreases dough resistance and induces dough stickiness. TNO developed Reuteran, which had shown to be a highly functional food fiber. Reuteran is an α1-4, α1-6 glucan produced by lactic-acid bacteria, *Lactobacillus reuterii*. Due to its highly specific structure, it acts synergistic with gluten. The addition of 2% Reuteran on flour weight basis has been discovered to restore the bread volume lost by reducing NaCl by over 50%. Furthermore, it overcomes dough weakness and stickiness resulting from 50–100% NaCl reduction without inducing buckiness or stiffness.

Sodium Reduction while Maintaining Shelf-Life and Safety

Sodium reduction may affect the shelf-life and safety of foods, since salt is a very effective preservative. Salt reduces the amount of water available for microbial growth (aw); hence, salt reduction may allow pathogenic or spoilage-causing microorganisms to grow more easily. It is therefore recommended to carefully judge the possible effects of reformulation, especially for products with a long ambient shelf-life or which are already critical.

To efficiently evaluate the effect of salt reduction on the shelf-life and safety of new formulations, TNO developed a high throughput challenge testing platform. Large amount of formulations can be made in multi-well plates and are inoculated with target microorganisms. At several points in time, DNA can be isolated and purified to determine cell counts using quantitative polymerase chain reaction (qPCR). This methodology allows us to accurately evaluate the shelf-life and safety of micro food systems with wide variation of formulations in parallel (33).

Sodium Reduction while Maintaining Taste Perception

A gradual sodium reduction over time in small cumulative steps may be an effective tool to realize sodium reductions in the diet (34). However, without compensation of the lower flavor intensity, the sensory profile of food products will deteriorate. Indeed, human volunteer studies (35) indicate that substantial reductions of ~25% are accepted. These results indicate that consumers taste preference adapts relatively fast.

As consumers choose freely between different food types and brands, a noticeable lower taste perception of a product should be prevented. Hence, this approach will be most effective in an industry-wide application. More information is still needed (e.g., on consumers' choices in a dynamic situation or depending on packaging information). In the Netherlands, the technological feasibility of food reformulation, the impact on consumer acceptance and behavior, and the effect on public health are being studied. In this integral project (36) between TNO, WUR, and RIVM it was determined that a multidisciplinary approach is essential when dealing with such a comprehensive challenge.

Salt Replacement by Substitutes

If we want to reduce the sodium content of food, but at the same time retain its sensory profile, several existing and new sodium-reduction strategies may be applied. To be able to create sodium-reduced products with improved sensory profiles, it is important to understand how different tastes are perceived. We have different types of taste receptors on our tongue. Sweetness, for instance, is perceived by binding of sucrose to the receptor. The binding site is not very specific, allowing for sweetness perception by other compounds (e.g., artificial sweeteners) as well. Saltiness is perceived via permeation of sodium ions through an ion channel in the cell membrane. This mechanism is much more specific. Besides sodium only lithium (toxic) and potassium (besides salty also bitter) are able to permeate through the ion channel.

Although artificial salt does not exist, the most common strategy is to replace sodium salts by other inorganic salts such as potassium chloride. It has been demonstrated that replacing 20% of sodium by potassium results in bread with an acceptable taste, whereas 40% replacement results in unacceptable off-taste (37). As a consequence, sodium replacement is limited.

Taste-Taste Interactions

It is known that different taste qualities interact, mutually influencing their perception (38). This allows for another strategy for sodium reduction, by the addition of other taste qualities which amplify the salty taste of sodium or mask the off-taste of potassium. An example of this approach already applied in practice is saltiness enhancement by umami compounds, e.g. yeast extracts, nucleotides. However, their application is limited as well, as they induce undesired savory notes. The combination of potassium and umami compounds is often advised as the umami compounds somewhat mask bitterness.

Multisensory Interactions

Every time a consumer eats or drinks, the information provided by the different modalities (i.e., taste, aroma, color, sound, and texture) accumulates into certain perceptions. By understanding the interactions between the modalities it is possible to enhance taste perception. The most clear multisensory interaction is between odor and taste. Lawrence et al. (39) studied the use of odors to enhance saltiness. They evaluated the associations between food names and saltiness, and found that the odors of foods associated to saltiness led to saltiness perception by smell. Addition of these odors to water and aqueous salt solutions led to salty taste perception or enhancement thereof. Addition of congruent odors that are associated to saltiness may thus be used to enhance saltiness of sodium-reduced products.

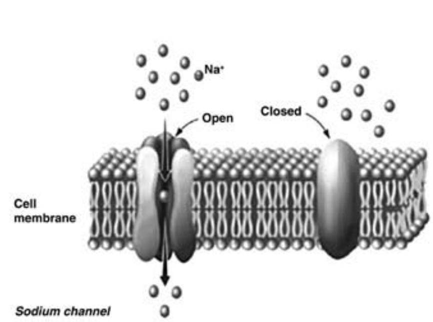

Fig. 12. Epithelial sodium channels can be opened or closed.

Stimulate Taste Receptors

As mentioned before, sodium receptors are highly specific. In addition, these channels can open and close. In a normal situation, only part of the receptors will be open and able to perceive sodium (Fig. 12). It is possible to amplify saltiness perception by stimulation of the receptors to open by compounds that stimulate the channels to open. In search of such compounds, TNO uses a voltage clamp system. This enables the permeation of sodium ions to be measured through the salt taste receptor (40). Using this approach, researchers hope to find new food grade compounds that stimulate the taste receptors to open, and hence to amplify saltiness perception of lower sodium concentrations.

Sensory Contrast

The creation of a sensory contrast in food products can amplify taste perception. Already in 1973 Meiselman and Halpern (41) showed that pulsed delivery of a salt solution enhanced the taste intensity when compared to a salt solution of the same overall salt content delivered in a continuous fashion. This sensory principle was successfully used to enhance saltiness intensity at lower overall salt content in bread by Noort et al. (42). They created an inhomogeneous distribution of salt in bread by means of alternating bread layers of high- and low-salt contents (Fig. 13). The salt content of breads could be reduced up to 28%, while remaining the same saltiness intensity and without taste-compensating additives. The magnitude of the saltiness enhancement increased with increasing salt concentration contrast in the bread products. This promising technology may be further developed to create sensory contrast based on an ingredient approach. TNO successfully applies this approach to create product specific solutions.

Developing Technology—Summary

There are many possibilities for innovations which enable us to create reduced-sodium products with excellent sensory properties, including salt substitution, taste-taste interactions, multisensory interactions, taste receptor simulation, and sensory contrast. One or possibly a combination of these techniques can be used to enhance flavor aspects of a reduced-sodium food product.

Consumers, health agencies, and governments are looking for sodium reduction. It is believed that reduction in sodium may help diminish health care costs by reducing the risks of cardiovascular-related diseases and other sodium-impacted illnesses, such as kidney damage, stomach cancer, and osteoporosis. On a global basis, the population has a dietary intake of sodium that exceeds the required level. Although the direct cause and effect in regard to HTN and sodium is not clear, there are organizations that feel that mandatory reduction in the sodium level in the diet is needed.

The strategies to achieve sodium reduction are not as simple as taking out salt- and sodium-based functional ingredients. Salt alone is a multifunctional ingredient. Salt contributes flavor, inhibits microorganisms, and enhances the quality characteristics of food products, such as baked goods, by optimizing volume and improving texture. Of all the replacement challenges, perhaps flavor is the most difficult to overcome. New strategies and technologies are being developed that will enable sodium reduction. A strategy for how to approach sodium reduction has been presented along with some new technologies to aid in sodium reduction.

It is anticipated that in the coming years, sodium reduction will take on a new focus.

If health is the concern, keep in mind the number of factors which impact cardiovascular health. There is evidence to say that sodium reduction alone may not be the answer. The inclusion of "positive" minerals, such as potassium, calcium, and magnesium, should be considered, since they may have an inverse impact on HTN—as they increase in level in the diet, HTN may be lowered. Weight loss is the other big tool. In this era of obesity—it might have the greater impact on cardiovascular health.

New tools will be launched—new strategies will be provided—salt and sodium reduction will continue to be a priority for the food and beverage industry.

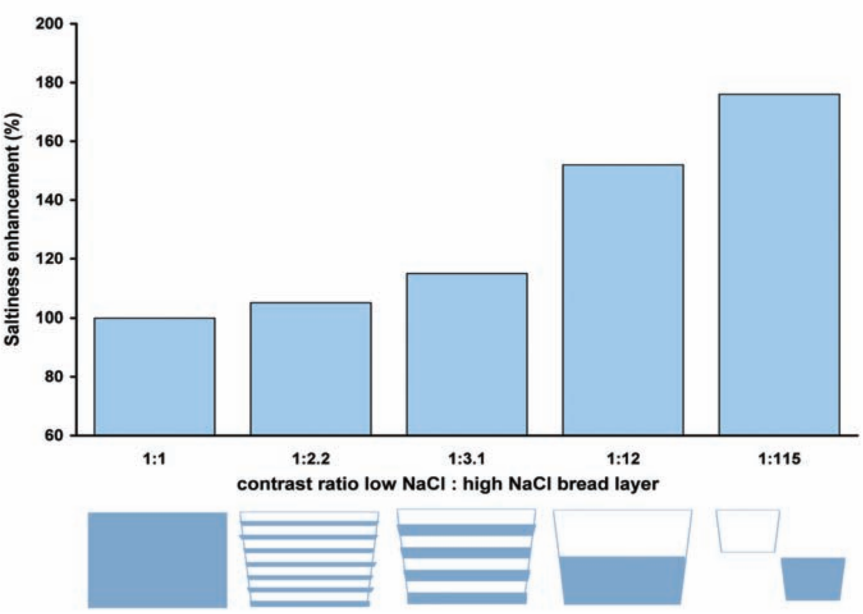

Fig. 13. Sensory contrast—Saltiness enhancement increases with contrast (42).

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