SALT AND BITTERNESS SUPPRESSION OF PHYTONUTRIENT COMPOUNDS

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ABSTRACT

Sodium chloride's very positive contributions to the human experience are historical, practical, nutritional and very complex. There exist multiple and important reasons for salt's consumption by humans, including: the sensory enhancement of foods; physiological health; food functionality including preservation and safety; and psychological wellbeing. However, whereas sodium chloride has been the object of considerable scientific, regulatory and public scrutiny, its many positive contributions to public health and wellbeing tend to be overlooked. Salt plays a positive role in boosting the consumption of healthful foods to which humans, especially children, would otherwise be averse. This includes vegetables rich in bitter-tasting phytonutrients. Sodium chloride functions as a bitterness inhibitor that allows humans to overcome their natural aversion to phytochemical-rich foods that protect against cardiovascular disease, cancer, and cerebrovascular disease (stroke), the three leading causes of human morbidity and mortality in Western societies. Any perceived public health risks linked to sodium consumption should be juxtaposed against salt's ability to enhance the palatability and, hence, the consumption of phytonutrient-rich vegetables that protect against those disease conditions associated with human aging and mortality, including hypertension.

Key Words: Salt, Phytonutrients, Bitterness, Vegetables

Introduction

Demand for salt has played historic roles in human history. No doubt, early nomadic humans, like the animals they hunted, sought out salt deposits wherever available. Japanese records describe extracting salt from boiled seaweed for use as a food preservative in 200 B.C.; Romans marched into Palestine in part to access its Dead Sea salt deposits in 67 B.C. and Romans of the time were paid in salt as a currency, a "salarium". During the 7th Century, the city-state of Venice grew into the preeminent Mediterranean power in part because of its salt-trading monopoly[1]. Salt may no longer trigger wars but the issues surrounding salt's contributions and appeal to human welfare are no less complicated.

Sodium chloride is a well known flavoring agent in foods and is used in a wide variety of cuisines. Salt is considered one of the basic tastes which also include sweet, sour, umami (savory), and bitter. Salt provides flavor enhancement and enjoyment to a variety of foods that might not otherwise be consumed. Not only does sodium chloride impart saltiness, but it can suppress undesirable tastes such as bitterness in vegetables. Although healthful, vegetables may be rejected by adults and especially children because of their bitter tastes. This is of concern because vegetables are important sources of phytonutrients, plant compounds that are associated with health benefits. This paper will address the positive role that salt can play in suppressing the bitter taste of phytonutrients in vegetables.

Contributions of Salt to Human Wellbeing

The contributions of salt to human wellbeing are highly complex, in large part because they are so intertwined with multiple interrelated factors. These include:

[1] Trager, J. "The Food Chronology" 1995; Henry Holt and Company, Inc., New York, NY.

- **Physiological:** The need for animals to balance their dietary intakes of sodium and potassium relates to the agonistic roles these cations play in physiological processes and osmoregulation. Consequently, dietary demand for salt is essential to survival and an important driver in salt consumption [2, 3]. Unsurprisingly, humans and other life forms have evolved sophisticated physiological mechanisms whereby to balance and self-regulate their intakes of sodium and potassium.

- **Food Functionality**: Two of salt's oldest recorded uses are in food preparation and preservation[1]. Salt affects the functionality of food ingredients and microbial growth by modifying the behavior of water molecules and increasing ionic strength in foods[4]. Salt's ability to sequester water molecules reduces water activity and chemical function of other ingredients, such as proteins and carbohydrates. It is by this mechanism that salt can alter the texture of foods and help ensure food safety through the inhibition of microbial outgrowth.

  Among many other uses, salt is incorporated to control fermentations in breads and meats, develop meat emulsions in lunchmeats, and control cheese curding and ripening. Additional functions include: strengthening gluten in dough, preventing frozen egg yolks from gelling, and enhancing water-holding capacity in meats and poultry. In the koshering process, salt is required to draw blood from meat or poultry tissue. Salt provides a necessary source of electrolytes in isotonic sports beverages as well as infant formulas[5].

- **Sensory:** Dubbed the "brilliant taste" [6], salt provides an intensely positive and pleasurable taste sensation. Umami, a savory taste imparted by glutamates and ribonucleotides, and sweetness also are associated with pleasurable tastes, explaining in part why umami, salt and sweet tastants are often applied topically to foods. While the other two taste sensations, bitterness and sourness, can be associated with positive flavor experiences (e.g., chocolate, coffee, and citrus), albeit usually in combinations with salty or sweet tastants, they are also associated with intense taste avoidance reactions, such as to poisons (bitterness) and microbial spoilage (sourness). Salt's taste impact and its modulation of other tastes and flavors is the most intensely complex of all the tastants and is highly concentration specific[7,8].

  Furthermore, salt can modulate food texture and the perceptions thereof. Salt solutions of various strengths appear to connote different mouthfeel sensations in different subjects, leading to descriptors such as "sharp", "tingle" or "rough"[9], and described in other terms such as "smooth", "oily", "warm" and "clean" or "full." Salt also interacts with food proteins and carbohydrates which can cause proteins to congeal, toughen or expel moisture, as in cheese or tofu manufacturing, for example[4].

- **Psychological:** The intensity or brilliance of sodium's taste impact is still in the process of being neurophysiologically mapped, but appears to be hard-wired to

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Salt and Sodium; Petition to Revise the Regulatory Status of Salt and Establish Food Labeling Requirements Regarding Salt and Sodium; Public Hearing; Request for Comments, 72 Fed Reg 59973. March 27, 2008.

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[7] Gillette, M. "Flavor Effects of Sodium Chloride", *Food Technology, 39(6):* 1985, 47-52, 56.

[8] Pangborn, R. M. "Taste Interrelationships" *Food Research,25:* 1960, 245.

[9] O'Mahoney, M. "Qualitative Description of Low Concentration Sodium Chloride Solutions" *Br. J. Psychol., 64(4)*: 1973, 601-606.

the need for animals to consume sodium for osmoregulatory purposes[2]. A deficiency in sodium thus causes the organism to search out sodium and potassium in the diet until an osmoregulatory balance has been restored. The consumption of sodium appears to be linked to pleasure centers in the brain via the renin-angiotensin-aldosterone system (RAAS), involving hormonal intermediaries such as adrenal mineralcorticoid aldosterone (ALDO), angiotensin II and vasopressin, with receptors in the kidneys, lungs, cardiovascular system and brain. Given these complex hormonal and neurological interrelationships, it should not be surprising should there be documented links between sodium consumption, sodium status and behavior.

Sodium depletion is associated with the development of salt cravings in humans and animals. Moreover, the removal of salt from diets has also been linked with the development of depression-like behaviors in humans, including moodiness, apathy and loss of appetite[3]. One study noted an apparent relationship between Chronic Fatigue Syndrome (CFS) and voluntarily imposed low-sodium diets that reversed upon administration of therapies that increased sodium retention[10]. In sum, there appears to be an association between the removal of salt from the diet and behavioral patterns that warrants further investigation.

- **Nutritional**: While considerable attention has been paid to nutritional requirements for sodium and potassium, less attention has been paid to the role that sodium chloride plays as a catalyst for improved nutrition. Salt's role as a vehicle for nutritional enhancement, such as through iodine fortification [11], may be underappreciated but it has had enormous public health benefit worldwide. In the United States, salt was first fortified with iodine in 1924 on a national basis which resulted in the elimination of goiter in this country[12]. Iodine is an essential nutrient which is necessary for the proper functioning of the thyroid gland. It is now known that iodine is necessary for proper brain development of the fetus. Even mild deficiencies of iodine in a newborn can result in slightly lowered IQ score in children[13].

The Phytonutrient Conundrum

Plant life exists under constant assault by the environment and from predation. To enhance their survivability, plants produce chemicals which function as antioxidants (to protect against the corrosive effects of oxygen) and pesticides (to protect against predation). Ames, in 1990, estimated that "99.99%" of the pesticides consumed in American diets were produced by plants to defend themselves[14]. These include compounds such as phenols, complex polyphenols, terpenes, isoflavones, glucosinolates, isothiocyanates and cyanides. These compounds are intensely bitter-tasting and serve to discourage predators from consuming the plants, thereby ensuring the plants' survival rates. Predators, such as humans, meanwhile, developed highly sensitive taste mechanisms whereby to detect and avoid bitter tastes associated with poisonous materials. The detection and aversion to bitter tastes in humans is genetically coded [15] through identified taste-receptor genes (termed TAS2R), that also appear to influence a preference for sweetness. One specific taste receptor (encoded by TAS2R16) was found by researchers to mediate responses to bitter and highly toxic cyanogenic glycosides: the researchers were

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[10] Bou-Holaigah, I., Rowe, P.C., Kan, J. and Calkins, H. "The Relationship Between Neutrally Mediated Hypotension and the Chronic Fatigue Syndrome" *JAMA, 274(12):* 1995, 961-967.

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[14] Ames, B., Profet, M. and Gold, L.S. "Dietary pesticides (99.99% all natural)" *Proc. Natl.Acad. Sci. USA,* *87:* 1990, 7777-7781.

[15] Mennella, J.A., Yanino Pepino, M., and Reed, D. R. "Genetic and Environmental Determinants of Bitter Perception and Sweet Preferences" *Pediatrics, 115(2):* 2005, 216-222

able to trace the genetic fingerprint for this receptor back to the earliest origins of humans in the Middle Pleistocene period in Africa, suggesting the very early contribution of bitterness detection to humans' evolutionary survival[16].

Ironically, whereas many of these bitter compounds produced by plants are designed to be toxic to predators, they can contribute health benefits to animals when consumed in smaller doses.

Phytonutrients that function as bitter toxins while conferring such benefits in small doses include organosulfur pesticides, such as glucosinolates found in cruciferous vegetables (a category that includes broccoli, cabbage, kale, Brussels sprouts, and bok choy)[17]. Glucobassicin, also known as a bitter mustard oil glycoside, has been found to be toxic in rats at elevated doses. Disruption of tissues in cabbage or mustard plants induces an enzymatic reaction (myrosinase) that lyses glucosinolates to produce pungent, repellent isothiocyanates and hydrogen sulfide, resulting in the "sulfurous" odor commonly associated with plants in the cabbage family[18], especially during food preparation. However, numerous studies have documented that the consumption of sulfurophane isothiocyanate-rich vegetables in the cabbage family exhibits a strong inverse correlation to cancer risks[19,20].

Other examples abound: flavonol antioxidants in cocoa, tea and red wines have been documented to benefit cardiovascular health[21,22]. Complex polyphenolic lignans, such as seicoisolariciresinol diglycoside (SDG), a lignan antioxidant found in high concentrations in flaxseed, have been found to express antitumerogenic activity in mice and for women suffering from breast cancer[23]. A recent and massive pan-European analysis of the eating habits of about 450,000 subjects over a six-year period found strong inverse correlations between total consumption of fruit and vegetables and reduced risks of colorectal cancers[24].

Consumption of fruits and vegetables can also influence blood pressure. The original Dietary Approaches to Stop Hypertension diet, referred to as the "DASH" diet, was a multi-center feeding study that found that diets emphasizing 8 – 10 servings of fruits and vegetables and low-fat dairy products substantially reduced blood pressure[25]. Even

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the DASH-Sodium trial demonstrated that consumption of this "combination diet" rich in fruits, vegetables and low fat dairy products reduced blood pressure at every sodium level tested[26].

Fruit and vegetable consumption in the U.S. falls well below where U.S. health authorities would like them to be. The "Dietary Guidelines for Americans 2005" [27], published jointly by the U.S. Dept. of Health and Human Services and U.S. Dept. of Agriculture, draw from the DASH Diet and the USDA Food Guide Pyramid [28] in recommending the consumption of 4-5 servings/day each of fruits and vegetables (based upon a 2,000 Kcal /day reference diet). USDA's Food Guide Pyramid[28] describes the health benefits of vegetable consumption as part of an overall healthy diet. These benefits include: reduced risk of stroke and cardiovascular disease, protection against certain cancers such as mouth, stomach, and colon cancer, and reduced risk of type 2 diabetes. As of 2005, the leading causes of mortality in the U.S. were coronary vascular disease (211.1 per 100,000 population), followed by cancer (183.8 per 100,000 population) and cerebrovascular disease, or "stroke" (46.6 per 100,000 population)[29]. For all three causes of mortality, their incidence increases with age.

According to a 2005 report published by the U.S. Centers for Disease Control and Prevention (CDC) [30], the Behavioral Risk Factor Surveillance System Survey of 305,504 adults found that only 33% of adults surveyed consumed two-or-more servings of fruit per day and 27% consumed three-or-more servings of vegetables per day. Dietary goals for fruit and vegetable consumption, therefore, are not being met. This raises a two-fold question: why is consumption so low and what can be done to increase the consumption of fruits and vegetables in line with stated public health goals?

One solution is to reduce the bitterness inherent to vegetables, as plant breeders and food manufacturers have been doing for ages[15]. However, the conundrum in these breeding programs has been that efforts designed to increase the palatability of vegetables also reduce the very phytochemicals that make increased consumption of fruits and vegetables nutritionally desirable.

The other alternative is to reduce the perceived bitterness of vegetables.

Physiology of bitterness perception

Both salty and bitter taste perceptions are unique in that they are linked to the survival chances of the organism. If salt is the brilliant taste, bitterness is the powerful, aversive taste. Bitterness sensitivity is acute in humans. It is also complicated. In addition, the nature of bitterness perception varies widely.

Both salt (Na^+) and sour (H^+) taste perceptions involve the direct diffusion of small ions through sodium ion channels into the taste receptors. By contrast, sweet and bitter taste receptors are designed to detect large molecules and consequently operate by activating lock-and-key mechanisms on the surface of the receptors[31]. By this mechanism, specific (large) molecules lock into specific molecular sites on the receptor surfaces and trigger an intracellular cascade of biochemical reactions via a gustducin ("G") protein complex that culminates in a neurotransmitter signal to the brain. The lock-and-key mechanisms of such TAS2R bitter taste receptors appear to be highly variable and sensitive to specific categories of bitter tastants.

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27 U.S. Dept. of Health and Humans Services, U.S. Dept. of Agriculture "Dietary Guidelines for Americans, 2005" 6th Edition. Washington, D.C.: U.S. Government Printing Office.

28 USDA. My Pyramid.Gov. Why is Important to Eat Vegetables? http://www.mypyramid.gov/pyramid/vegetables_why.html. Accessed April 26, 2009

29 Statistical Abstracts of the United States, 2009; U.S. Census Bureau, Table 112.

30 Blanck, H.M, Galuska, D.A., Gillespie, C., Khan, L.K., Serdula, M.K., Solera, M.K., Mokdad, A.H., Cohen, L.P. "Fruit and Vegetable Consumption among Adults – United States, 2005" *Morbidity and Mortality Weekly Report, 56(10):* 2007, 213-217.

31 McGregor, R.M. Taste Modification in the Biotech Era. *Food Tech, 58:* 2004, 24-30.

The subject of considerable research to date, there may be 25 or more (some estimates put it as high as 80) such families of TAS2R taste receptors that are in the process of being categorized[32,33]. It has been suggested that each bitter taste receptor cell contains a diverse array of such lock-and-key binding sites (i.e., different locks requiring different keys) and is thus able to detect a varied arsenal of bitter molecules[34]. It is this diversity in bitterness sensitivity of such arrays and the variety of molecules that they are designed to detect that renders it so unlikely that a general bitterness inhibitor (i.e., a "master key") exists…except, that is, for sodium.

Role of Salt in Bitterness Mitigation

Studies at Michigan State University by Frank and Mickelsen[35] found that salt masked the bitter taste of potassium chloride. A group of 72 panelists tasted aqueous solutions of 0.064% potassium chloride which 67% rated as bitter. When 0.1% sodium chloride was added, the percentage of panelists reporting that the solution was bitter was reduced to 11%. Their other evaluations of differing levels of salt and potassium chloride showed similar results.

In a survey of taste interactions between various chlorides and sodium salts with an array of bitter compounds (e.g., urea, caffeine), it was observed that sodium ions effectively suppressed bitterness without any perceived loss in saltiness[36].

Further work demonstrated that changing the anion attached to the sodium ion had no effect on bitterness suppression but did affect saltiness perception: the bigger the anion (gluconate versus chloride, for example), the less salty the perception. Thus, sodium chloride offers the most effective combination of both bitterness inhibition and salty-taste perception. Interestingly, sodium's suppression of bitterness was also accompanied by an enhancement of perceived sweetness[37]. Researchers have suggested that salt suppresses bitterness and allows more desirable tastes such as sweetness to be tasted. They explain that mixtures of bitter and sweet compounds mutually suppress each other. When a salt is added, it suppresses bitterness more than the sweetness resulting in a mixture that tastes sweeter[38].

Gillette and co-workers conducted descriptive analysis testing which profiled the impact of adding 0.3% sodium chloride to unsalted split-pea soup. They found that the added sodium chloride significantly reduced the metallic and bitter taste notes of the soup while simultaneously increasing the perceived saltiness, sweetness, flavor strength, fullness, thickness and "balance" of the soup, all changes which presumably rendered the split pea soup more palatable[7] and would be expected to increase its likelihood of consumption.

Thus, sodium's functional role in changing the taste appeal of phytonutrient-rich vegetables could be multifold: a suppression of the bitterness contributed by phytonutrients; an enhancement of the sweet taste perception contributed by natural sugars in the vegetables; the enhanced perceptions of other positive flavor notes and the improvement of perceived textural qualities.

Salt Role in Increased Broccoli Palatability

Both young children and mature adults stand to gain from the consumption of vegetables – young children because of the nutritional

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value (vitamins, minerals, antioxidants) inherent to vegetables and mature adults because of the protective effects of phytonutrients on disorders associated with aging. Young children are particularly susceptible to bitter taste perceptions[15], while the aversion of adults to bitter tastes declines (fortuitously, it appears) with age even as their salty taste perceptions remain constant[39]. Loss of overall taste perception in mature consumers appears to be attributable to a multiplicity of factors, including normal aging, disease states, medications and other factors[40]. Thus, for mature consumers, the challenge is not so much to reduce the level of perceived bitterness in foods but rather to increase the overall palatability of foods.

Thus, children and adults all stand to benefit from increasing their consumption of fruit and vegetable servings. This should be especially true for glucosinolates- and isothiocyanate-rich cruciferous vegetables such as broccoli.

In a recent study conducted at Ohio State University[41], cooked broccoli florets were fed to three age groups – children (9-12 years old), adults (18-55), and mature adults (60+ years of age) - with different levels of salt addition. The researchers found that, for children and mature subjects, the taste preference for broccoli was increased with increased levels of table salt addition up-to 350mg /85g serving of broccoli, the maximum level of salting tested for these two groups.

Adults exhibited taste preferences that peaked between 350 and 450mg of salt addition, and flattened-out thereafter up to a maximum 750mg of added salt. For children and young adults, perceived bitterness decreased with increasing levels of salt addition, whereas mature subjects detected no differences in bitterness perception at all salting levels tested. As previously indicated, bitterness perceptions attenuate with age.

The results demonstrate how the addition of salt can improve the palatability of phytonutrient-rich cruciferous vegetables traditionally associated with bitter tastes. An interesting follow-up to this study might be to evaluate levels of broccoli consumption at different levels of salting under free choice feeding conditions: does the salting of broccoli increase the quantity thereof consumed at a sitting?

Conclusion

Subjects fed the DASH diet demonstrated that increased fruit and vegetable consumption led to very significant reductions in diastolic and systolic blood pressures in both hypertensive and non-hypertensive consumers. The overwhelming evidence suggests that increased consumption of phytonutrients will have beneficial effects on longevity and morbidity related to disorders such as cardiovascular disease, cancer, cerebrovascular disease, the three leading causes of mortality. The evidence suggests that sodium chloride can play an important role in overcoming the natural bitterness of vegetables rich in healthy phytonutrients with significant preventative effects for the leading causes of morbidity and mortality in society.

Salt's role in human nutrition and welfare is highly complex and it plays an important and beneficial role in increasing the consumption of phytonutrient-rich foods, a contribution that falls well in line with U.S. public health policy goals. This suggests that the multiple cost-benefit trade-offs associated with a potential reduction in salt consumption by the general public bear careful scrutiny and consideration. A more thorough understanding of the role that salt can play in enhancing the palatability and consumption of phytonutrient-rich foods would help to place the risk-benefits relationships of sodium consumption in a much better perspective than is currently portrayed in the public domain.

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