Literature Review

Salt; Health, Functionality and Flavor

Nu-Tek Products

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Setting the Scene

The April 2010 release of the Institute of Medicine report (Medicine, 2010) on salt (sodium chloride, NaCl) levels in processed foods sends a strong warning to the food industry about future changes in their use of sodium. Food companies will need to reduce levels of sodium in foods as mandatory national standards have been recommended. Excessive salt consumption is a major health problem for developed Nations. What follows is a brief summary of the IOM report including it’s recommendations.

Institute of Medicine Report on Salt 2010

*Americans consume unhealthy amounts of sodium in their food, far exceeding public health recommendations. Consuming too much sodium increases the risk for high blood pressure, a serious health condition that is avoidable and can lead to a variety of diseases. Analysts estimate that population-wide reductions in sodium could prevent more than 100,000 deaths annually. While numerous stakeholders have initiated voluntary efforts to reduce sodium consumption in the United States during the past 40 years, they have not succeeded. Without major change, hypertension and cardiovascular disease rates will continue to rise, and consumers will pay the price for inaction.*

*In 2008, Congress asked the IOM to recommend strategies for reducing sodium intake to levels recommended in the Dietary Guidelines for Americans. In this report, the IOM concludes that reducing sodium content in food requires new government standards for the acceptable level of sodium. Manufacturers and restaurants need to meet these standards so that all sources in the food supply are involved. The goal is to slowly, over time, reduce the sodium content of the food supply in a way that goes unnoticed by most consumers as individuals’ taste sensors adjust to the lower levels of sodium.*
Strategies to Reduce Sodium Intake in the United States from IOM Report

**Recommendation 1:** The Food and Drug Administration (FDA) should expeditiously initiate a process to set a mandatory national standards for the sodium content of foods.

**Recommendation 2:** The food industry should voluntarily act to reduce the sodium content of foods in advance of the implementation of mandatory standards.

**Recommendation 3:** Government agencies, public health and consumer organizations, and the food industry should carry out activities to support the reduction of sodium levels in the food supply.

**Recommendation 4:** In tandem with recommendations to reduce the sodium content of the food supply, government agencies, public health and consumer organizations, health professionals, the health insurance industry, the food industry, and public-private partnerships should conduct augmenting activities to support consumers in reducing sodium intake.

**Recommendation 5:** Federal agencies should ensure and enhance monitoring and surveillance relative to sodium intake measurement, salt taste preference, and sodium content of foods, and should ensure sustained and timely release of data in user-friendly formats.
1.0 Introduction

Sodium chloride (NaCl) is the prototypical stimulus that elicits salty taste. Sodium chloride is a commonly used food ingredient which provides many technological functions such as flavour enhancement, preservation and texture modification (Hutton, 2002). Sodium (Na\(^+\)) also performs a number of vital roles in the body including maintaining the volume of extracellular fluid, osmotic pressure, acid-base balance and transmission of nerves impulses (Geerling & Loewy, 2008). Unlike other essential minerals such as calcium, we do not have large stores of sodium in the body and need to constantly replenish sodium via the diet (Reddy & Marth, 1991).

While sodium is essential for normal human functioning, current sodium intakes far exceed recommendations for good health (Brown et al., 2009). This is a problem because there is a strong positive relationship between sodium intake and blood pressure. Raised blood pressure is a major cause of cardiovascular disease, responsible for 62% of stroke and 49% of coronary heart disease (He & MacGregor, 2010). Excess sodium consumption has also been linked to numerous other negative health effects including gastric cancer (Tsugane et al., 2004), decreased bone mineral density (Devine et al., 1995) and possibly obesity (He et al., 2008).

In general, attempts to reduce dietary sodium intake through sodium restricted diets have shown short term success but have lacked long term sustainability and practicality for large populations due to high levels of sodium in processed foods and the significant contribution of processed foods to our diet (James et al., 1987; Hooper et al., 2002b). Also, a reduction of sodium chloride in foods is accompanied by a loss of palatability of those foods (Mattes, 1997; Karanja et al., 2007a). The ideal solution would be to reduce the concentration of sodium in the food while retaining optimum saltiness for palatability. One strategy to reduce sodium is to replace with potassium salts, and while potassium chloride elicits weak saltiness, at higher concentrations it also elicits metallic and bitter taste limiting its utility in foods (Ainsworth & Plunkett, 2007). However, minimising those ‘off-flavors’ means potassium could be an effective salt taste replacer.
1.1 Significance
Excess sodium consumption has been linked to numerous adverse health conditions and is a major public health concern in the USA and worldwide (Medicine, 2010). Previous strategies to reduce sodium chloride consumption have shown to be effective in health care settings but are not practical at the population level due to the large contribution of processed foods to sodium intake. Strategies aimed at lowering the sodium content of processed foods have the potential to decrease sodium in the food supply, thereby decreasing population wide sodium consumption. Even small decreases in diastolic blood pressure (DBP) (-2 mmHg) as a result of sodium reduction can reduce the prevalence of hypertension by 17% (Cook et al., 1995). While decreasing sodium is causal in reducing hypertension (World Health Organisation, 2003), the totality of existing evidence suggests that both low sodium and high potassium intakes are necessary for the greatest protection against high blood pressure and development of CVD (Intersalt Cooperative Research Group, 1988; Poulter et al., 1990; Cook et al., 2009).
2.0 Physiological roles, intake recommendations and current consumption patterns of sodium and potassium.

2.1 Sodium
Sodium is responsible for regulating extracellular volume, maintaining acid-base balance, neural transmission, renal function, cardiac output and myocytic contraction (Dotsch et al., 2009). While there is variability in individual sodium requirements the World Health Organisation recommends that an adult adequate sodium intake is <87 mM/day (<5g) (World Health Organisation, 2003). The average US sodium intake is estimated to be 140-160 mM/day (8-9.5 g/day) (Wright et al., 2003; Cordain et al., 2005; Cook et al., 2007) and United Kingdom (161 mM/day (9.5g/day). These studies illustrate we are consuming levels well in excess of sodium required for optimum health.

2.2 Potassium.
Potassium is an essential dietary micronutrient responsible for smooth muscle contractility, fluid balance, neural signal transduction and cardiac function (Wardlaw & Hampl, 2007). Adequate intake for the prevention of chronic disease for potassium is 120 mM/day (4.6g) (World Health Organisation, 2003; Champagne, 2006). The NHANES survey revealed the median potassium intake to be 49.8 mM (g)/day (Bazzano et al., 2001). In contrast to sodium, these studies demonstrate that we are consuming potassium below intake guidelines.

2.3 Inversion of potassium and sodium intake.
Arguably, the human diet has undergone more significant changes in the past 50 years than in the past 10 million (Cordain et al., 2005). One such modification is the molar ratio consumption of sodium to potassium. Historically hominid diets contained high potassium and low sodium concentrations due to a diet consisting largely of fruits, vegetables and whole grains (Cordain et al., 2005). Our evolutionary forebears had a need to consume sodium, and as sodium was a scarce dietary element, we developed an appetitive response to sodium via salt taste (Mela, 2006). Although the taste mechanism for sodium has not changed, the food supply has developed to suit our appetitive desires and the modern western diet contains a high proportion of processed foods with high levels of sodium, which is inherently appealing to humans (Mattes, 1997). Moreover, fruit and vegetables are the main source of dietary
potassium, however fruit and vegetables are not adequately consumed in a western style diet. Overall consuming a western style diet has resulted in a decreased intake of potassium and increased intake of sodium (Figure 1).

**Figure 1**: Changes in sodium (Na) and potassium (K) intake in the transition from ancestral (Then) to current (Now) diet (Frassetto *et al.*, 2001). The graph demonstrates sodium concentration increasing while potassium concentration declines during the transition from the ancestral to the current diet.
3.0 Health effects of sodium and potassium intake

The excess sodium and insufficient potassium consumption that is associated with a typical western style diet have been linked with several negative health effects which are outlined in the following sections.

3.1 Blood Pressure

3.1.1 Sodium and blood pressure
The relationship between sodium intake and blood pressure is well established. Numerous systematic reviews and meta analysis have been found to support a positive linear association between sodium intake and increasing blood pressure (Intersalt Cooperative Research Group, 1988; Stamler, 1991; Stamler, 1997; He et al., 2002; Hooper et al., 2002b). This association was depicted in the large worldwide epidemiological study INTERSALT which reported the relationship between sodium and potassium excretion and blood pressure of 10,079 men and women across 52 centres. A significant positive linear relationship was found between sodium intake and systolic blood pressure (Figure 2) when adjusted for age, sex, BMI and alcohol consumption (P<0.001) (Intersalt Cooperative Research Group, 1988).

Figure 2: The association between sodium excretion and systolic blood pressure (Intersalt Cooperative Research Group, 1988). Depicted is a positive linear relationship between sodium intake and systolic blood pressure.
The linear relationship is supported by another meta-analysis which illustrate significant reduction in blood pressure with a decline in sodium intake. He and MacGregor (2002) found that a sodium decrease of 78 mM/day (4.5g) in hypertensive individuals equated with 4.96mmHg fall in systolic blood pressure (P<0.001). In addition, in normotensive individuals a 74mmol/day (4.4g) reduction in sodium caused a decrease of 2.03mmHg (P<0.001). The meta-analysis findings are supported by previous conclusions that reductions in sodium affect hypertensive individuals to a greater degree than normotensive individuals (Geleijnse et al., 1997; Sacks et al., 2001a; He & MacGregor, 2002; Geleijnse et al., 2003) Furthermore, these findings were based on modest sodium reduced diets in adults over a minimum intervention period of four weeks which demonstrates that there is likely to be a long term effect of sodium reduction on blood pressure.

3.1.2 Potassium and blood pressure
Both epidemiologic and clinical studies have suggested that an increase in potassium intake may lower blood pressure. A meta-regression analysis of randomised control trials by Geleijnse, Kok and Grobbee (2003) found that a median potassium increase of 44 mM/day (1.7g) corresponded in a fall of 2.2/1.6mmHg (systolic/diastolic) after adjusting for potential confounders. These results appear conservative in comparison to an earlier meta analysis of clinical trials by Cappuccio and MacGregor who witnessed a 6/3mmHg (systolic/diastolic) decrease in blood pressure with oral potassium supplements (Cappuccio & MacGregor, 1991). The difference in results could be attributed to Geleijnse, Kok and Grobbee excluding short term trials from the meta-regression and Cappuccio and MacGregor only using a hypertensive population group for interventions.

3.2 The Sodium Potassium Ratio
Some studies have shown the effect of the sodium potassium ratio on blood pressure and cardiovascular disease to be more significant than the effect of either electrolyte considered individually (Khaw & Barrett-Connor, 1988; Poulter et al., 1990; Cook et al., 2009). The consequences of increased sodium consumption in tandem with decreased potassium consumption has been explored in populations moving from rural to urban areas.
The Kenyan Luo Migration study showed rural farmers that traditionally consumed a diet very low in sodium experienced increased blood pressure after an average of one month post migration to urban areas (Poulter et al., 1990). As well as consistently having significantly higher systolic and diastolic blood pressures than their rural counterparts, urbanised men and women also had significantly higher urinary sodium and lower urinary potassium excretions suggesting that both low dietary intake of potassium and high intake dietary intake of sodium to be associated with increased blood pressure (Poulter et al., 1990). The Trials of Hypertension Prevention (TOHP) follow up study found when urinary sodium potassium ratio was tested for a relationship with CVD a significant, positive and linear relationship that was similar for stroke and CHD morbidity and mortality and was not affected by age, sex, race, baseline BMI or smoking (Cook et al., 2009).

Overall there has been limited research into the relationship of the sodium potassium ratio to health. However, the totality of existing evidence suggests that both low sodium and high potassium intakes are necessary for the greatest protection against high blood pressure and CVD (Intersalt Cooperative Research Group, 1988; Poulter et al., 1990; Xie et al., 1992; Dyer et al., 1994; Cook et al., 2009). Figure 3 shows the relationship between sodium, potassium and blood pressure.
High sodium intake -> Renal sodium retention -> Sodium excess -> Increased extracellular volume

Low potassium intake -> Renal potassium excretion -> Potassium deficit

Release of digits-like factor -> Inhibition of sodium-potassium ATPase pump

Increased intracellular concentration of sodium

Decreased intracellular concentration of potassium

Smooth muscle contraction

Increased peripheral resistance

Increased blood pressure

**Figure 3:** Sodium and Potassium in the Pathogenesis of Hypertension. Adapted from (Androgue & Madais, 2007).

### 3.3 Cardiovascular Disease

High blood pressure is a strong risk factor for cardiovascular disease and stroke (World Health Organisation, 2002). It has been estimated that a decrease in systolic blood pressure of 2mmHg would result in a 4 % reduction cardiovascular disease risk and overall mortality by 3% (Chobanian *et al.*, 2003).
Studies linking sodium intake and reduced cardiovascular disease risk have shown conflicting results. A possible reason for this is the inconsistency of definitions used to describe cardiovascular events, different methodological approaches used, differences in population groups and sodium measurement methods (Hooper et al., 2002b). However, a meta-analysis of prospective studies by Strazzullo et al (2009) found an association between higher sodium intake and cardiovascular disease risk in a pooled analysis of 14 cohorts (Strazzullo et al., 2009).

### 3.4 Stroke

A meta-analysis of prospective studies by Strazzullo et al. on the effects of sodium intake on stroke and cardiovascular disease illustrated that a high sodium intake was associated with greater risk of stroke (P=0.007) (Strazzullo et al., 2009). Results from prospective studies of stroke risk and potassium intake have shown inconsistent findings however, a majority support an inverse relationship between stroke risk and increased dietary potassium intake.

Bazzano et al. studied potassium intake and stroke risk of 9805 men and women who participated in NHANES I epidemiologic follow-up study. It was found that those who had insufficient potassium intake had a 28% greater risk of stroke (P=0.001) (Bazzano et al., 2001). Potassium intake was obtained from 24 hour diet records which are prone to confounding. A study of 43,738 male health professionals by Ascherio et al. also documented an inverse relationship between risk of stroke and potassium intake (Ascherio et al., 1998).

### 3.5 Summary

Table 1: Summary of health effects related to sodium and potassium consumption

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<td><strong>Sodium</strong></td>
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<td>• ↑ Sodium intake = ↑ Blood Pressure</td>
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<tr>
<td>• ↑ Sodium intake = ↑ Risk of Cardiovascular Disease</td>
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<td>• ↑ Sodium intake = ↑ Stroke Risk</td>
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<td><strong>Potassium</strong></td>
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<td>• ↑ Potassium intake = ↓ Blood Pressure</td>
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<td>• ↑ Potassium intake = ↓ Stroke Risk</td>
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4.0 Flavour Perception

Flavour is a multimodal sensory experience incorporating inputs from all our senses: sight, hearing, touch, smell and taste. While all sensory systems are involved in flavour perception, it is the chemical senses, taste, smell and chemical irritation, that provide the majority of information about the flavour of the food or beverage (Keast et al., 2004a). Arguably the most important sensory system regarding the acceptance or rejection of food is the sense of taste, as it is a proximal sense that determines whether a food carries potential nutrients or toxins. To perform this task the taste system is subserved by five taste qualities: sweet, sour, salty, bitter and umami. Taste sensations are characterized by four separate attributes – quality, intensity, temporal and spatial patterns (Keast et al., 2004a). Taste quality is the most important defining feature of taste sensation and it is a descriptive noun given to categorize sensations that taste compounds elicit (sweet, sour, salty, bitter and umami). Intensity is related to the magnitude of the taste sensation and may be plotted against its concentration to produce a psychophysical function. Temporal pattern is used to describe the time course of taste perception and intensity. And spatial topography relates to location and localizability of taste sensation (Keast et al., 2004a). Regarding spatial topography, it is important to note the oft recited theory of the tongue map is incorrect, anywhere we have papillae or taste receptor cells we can experience all tastes.

4.1 Taste Transduction and taste thresholds

Taste transduction is initiated when sapid compound activates taste receptors throughout the oral cavity. Taste receptors are found on taste receptor cells, housed in groups of 50-100 cells in taste buds. Taste buds themselves are housed in specialised epithelial structures named papillae. Papillae have three different structural forms fungiform at the anterior tongue, foliate at the side of the tongue, and circumvallate at the posterior tongue. Once the taste receptor is activated, afferent nerve fibres then transmit this information to the gustoral cortex of the brain where it is coded into a taste response (Chandrashekar et al., 2006).

As the concentration of a sapid compound increases, it may reach different levels of perception. Taste is initiated when a sapid compound activates taste receptor cells but the concentration may be too weak to produce a cognitively noticeable electrical impulse; although the compound is present no taste is perceived. As the concentration of the compound increases a level will be reached when an individual will be able to discriminate
from water but unable to identify the taste quality, this is known as the detection threshold. Taste identification occurs when the concentration of the sapid compound is enough to not only activate the taste receptor but produce an electrical impulse which can be carried via afferent fibres to the brain where it is decoded and the taste quality identified; this is known as the recognition threshold (Keast & Roper, 2007). As the concentration of the tastant increases further, the perceived intensity of the tastant also increases.

4.2 Salt taste
Recent advances in salt taste transduction illustrate the complexity involved in chemoreception. Sodium and Lithium are the only two minerals known to elicit a pure salty taste, other minerals can elicit some salt taste however it is often mixed with metallic or bitter flavours. Lithium is toxic when ingested in moderate quantities and therefore is not added to foods. Using an animal model, Chandrashakar et al (2010) demonstrated there are two epithelial sodium channels on taste receptor cells, one that is permeable only to sodium, and one that is non-specific and is activated by other mineral cations including potassium. The sodium specific channel is believed responsible for the appetitive nature of sodium in foods, while the non-specific channel may be responsible for some of the aversive nature of various cations (Chandrashekar et al., 2010). It is thought that the ion channel for salt taste are not located on the apical surface of the taste cell, but rather on the paracellular region between taste cells (Keast & Breslin, 2002a).

5.0 Taste Interactions
As a general rule, when we taste a solitary compound in water as the concentration of the compound increases so too does our perceived intensity. However, singular taste stimuli are rarely encountered in everyday life. A number of interactions can occur when two or more taste stimuli are mixed. For example, mixture suppression can occur when two or more suprathreshold stimuli of the same modality are mixed together, the intensity is less than the sum of the individual (unmixed) intensities (Keast et al., 2004b). In other words suppression results in a taste sensation which is less than the sum of its components (i.e 1 + 1 < 2). Enhancement is in direct opposition of suppression and refers to when two or more supra threshold stimuli are mixed together, the intensity is greater than the sum of the individual
(unmixed) intensities (Keast et al., 2004b). Enhancement results in a sensation which is greater than the sum of its components (ie. $1 + 1 > 2$).

5.1 Three levels of taste interactions
Interactions in taste mixtures such as mixture suppression and enhancement can occur at three different levels – in a food/beverage prior to ingestion, oral physiological interactions or central cognitive interactions (Keast et al., 2004a). Interactions in a food or beverage are common and can result in tastants being trapped in a matrix and unavailable for taste reception, such as happen with sodium in bread. Oral physiological interactions involves one compound interfering with taste receptor cells or taste transduction mechanisms associated with another compound and are classified as peripheral interactions as they occur at the cellular/epithelial level (Keast & Breslin, 2005). Cognitive interactions refer to central processing of taste stimuli after afferent signals are sent to taste processing regions of the brain. Central cognitive interactions are generally responsible for mixture suppression and caused during processing of signals in taste and smell processing regions of the brain (Kroeze & Bartoshuk, 1985a; Keast & Breslin, 2005).

5.2 Taste interactions involving saltiness
Keast and Breslin reviewed salt taste interactions and reported at low concentration NaCl saltiness was enhanced by KCl, while at higher concentrations it was suppressed (Breslin & Beauchamp, 1995a; Keast & Breslin, 2003). Salt and sour mixtures symmetrically affect each others’ intensity with enhancement at low intensity/concentrations and suppression or no effect at high intensities/concentrations (Beebe-Center et al., 1959; Pangborn, 1960b; Kamen et al., 1961; Pangborn, 1962; Kroeze, 1979; Kroeze, 1982; Lawless, 1982; Gillette, 1985; Kroeze & Bartoshuk, 1985b; Schiffman et al., 1985; De Graaf & Frijters, 1989; Frank et al., 1993; Schifferstein & Frijters, 1993; Frijters & Schifferstein, 1994; Breslin & Beauchamp, 1995b; Stevens, 1995; Breslin, 1996; Breslin & Beauchamp, 1997; Stevens & Traverzo, 1997; Prescott et al., 2001; Keast & Breslin, 2002b; Keast & Breslin, 2002c). Bitterness is suppressed by salt while salt taste is not affected by bitterness. Salt enhances sweetness at low concentrations, has variable effects through the moderate intensity/concentration range, and is suppressive or has no effect on sweetness at higher intensity/concentration. Sweetness suppresses salty taste at moderate intensities (Keast & Breslin, 2003).
Peripheral interactions have an influence in multi-component mixtures. Breslin et al. (Breslin & Beauchamp, 1997) examined the interaction between sodium, sucrose and urea. They asked, What happens if a sodium salt is added to the bitter-sweet mixture, given that sodium salts inhibit bitterness and bitterness and sweetness are mutually suppressive? The results showed that addition of sodium to a bitter-sweet mixture suppressed the bitterness. As the intensity of bitterness decreased, sweetness was enhanced due to release from cognitive suppression of the bitterness. A similar study was performed with similar results by Keast and Breslin (Keast & Breslin, 2005). These three-taste interaction studies illustrate the complexity involved in understanding taste interactions and show how peripheral and central cognitive effects can interact.

5.3 Taste Interactions in Food Matrices

The most influential researcher in the area of taste in various matrices or food systems was Pangborn (Pangborn, 1960b; Pangborn, 1960a; Pangborn, 1961; Pangborn, 1962; Pangborn et al., 1963; Pangborn & Hansen, 1963; Pangborn & Chisp, 1964; Pangborn et al., 1964; Pangborn & Trabue, 1964; Pangborn, 1965; Pangborn & Trabue, 1967; Pangborn et al., 1973; Pangborn et al., 1978; Pangborn, 1987). Pangborn and colleagues performed a series of experiments in the early 1960’s investigating sucrose, citric acid and NaCl taste interrelationships. Several different food matrices were used, e.g., pear nectar (Pangborn, 1960b), tomato juice (Pangborn & Chisp, 1964), and lima bean puree (Pangborn & Trabue, 1964). The results from the food matrix generally supported results mentioned in section 5.2.

Breslin et al, (1997) demonstrated that sodium salt suppressed bitterness and also increased sweetness by releasing it from the mixture suppression exerted by the bitterness. This was demonstrated in food matrices: Gillette (Gillette, 1985) reported that addition of NaCl to three soups decreased bitterness and increases sweetness, while Fuke & Konosu (Fuke & Konosu, 1991) reported that addition of umami tasting sodium salts of 5’-ribonucleotides (which suppress bitterness) reduced bitterness and increased sweetness in an artificial prawn extract.

Apart from the primary taste response of adding a compound (NaCl increasing saltiness), the secondary and tertiary results such as suppressions, release of suppression, or enhancements
can often be predicted. There are parallels between simple solutions used in psychophysical studies and the more complex food matrices. However, sapid compounds added to a matrix may behave differently than predicted, and matrix effects should not be underestimated (Keast & Breslin, 2003).

6.0 Strategies for sodium reduction

6.1 Rationale, costs and benefits of a sodium reduction program.

The current sodium intake in developed Nations doubles exceeds the <87 mM/day (5g) recommendation for disease prevention (World Health Organisation, 2003). High sodium consumption is linked with both increased blood pressure and risk of cardiovascular disease. The magnitude of potential health gains achievable through population based sodium reduction are highly significant (Asaria et al., 2007; Webster et al., 2009). A report by Asaria et al (2007) calculated that a modest 15% reduction in population sodium intake, could avert 8.5 million cardiovascular related deaths worldwide over 10 years (Asaria et al., 2007). Decreasing sodium intakes would assist the prevention of age related rises in blood pressure and therefore cardiovascular disease risk (Neal et al., 2006). Age related increases in blood pressure and cardiovascular disease are likely to become more prolific with the current ageing population.

A comprehensive meta analysis prepared by the WHO concludes that there is very strong evidence for the cost effectiveness of national sodium reduction strategies (Neal et al., 2006; Asaria et al., 2007). For example, cardiovascular diseases are the most expensive health issue accounting for 11% of total health expenditure (AIHW, 2005). The average sodium reduction strategy is expected to cost only a fraction of the cost to treat CVDs.

6.2 Methods of sodium reduction

The evidence supporting high sodium intake and negative health effects has lead to the research on methods of sodium reduction which are discussed below.
6.2.1 Sodium restricted diets
Sodium restricted diets have been shown to be effective at reducing blood pressure however, support is often required in the form of extensive dietary counselling or in the provision of low salt food products. Community based intervention trials have demonstrated that only 20-40% of participants were able to reduce their sodium intake below the upper intake of 100mM/day despite intense counselling. (Karanja et al., 2007b). Due to the need for counselling, this intervention would not be feasible at a population level. Sodium reduced diets are often hard to maintain as they require a change in dietary behaviour, for example, actively choosing low salt foods. This behavioural change is difficult to develop. Additionally, having an innate liking for salt taste in a food environment rich in sodium makes compliance with low sodium diets difficult. Hooper and Sacks suggested that an overall sodium reduction could be more effectively achieved by reducing the sodium content of processed foods than by just giving dietary advice alone (Sacks et al., 2001b; Hooper et al., 2002a; NHF, 2006).

6.2.2 Food industry strategy for sodium reduction
Processed foods contribute 75% to total sodium intake (James et al., 1987), therefore sodium reductions within these foods could significantly contribute to an overall dietary decrease in sodium. A World Health Organisation (WHO) report, Reducing Salt Intake in Populations, underlines the need to work directly with food manufacturers as a cornerstone of any successful national salt reduction campaign (World Health Organisation, 2006). A food industry strategy is an important component of many sodium reduction programs worldwide.

6.3 Methods of sodium reduction in the food industry
Many countries now have implemented some kind of sodium reduction program, however the United Kindom (UK) and Finland are the only countries to have strategies with proven decreases on population sodium intakes (Webster et al., 2009). While the two strategies are similar in their approaches using public health promotion and a sodium labelling system, where they differ is in their methods of sodium reduction from within food industry.

6.3.1 The United Kingdom strategy - sodium reduction by stealth
The UK approach is based around stealth reduction methods which refers to a gradual reduction of salt in processed foods that is unnoticeable to consumers (Kilcast & Ridder,
The foundation of the approach is based on setting sodium reduction targets for different product categories which industry are expected to meet within an allocated time period. This strategy has been successful with the sodium content of most processed foods in supermarkets being reduced by 20-30% in the past 3 years. These results are expected to be duplicated when revised targets are set for a further 10-20% reduction to meet the UK’s daily intake target of 6g/day by 2012 (He & MacGregor, 2008).

6.3.2 The Finnish strategy: Use of salt substitutes

The Finnish food industry has a different approach to reduce sodium in processed foods. Companies have been reducing sodium in food products by replacing NaCl (salt) with sodium-reduced, potassium and magnesium enriched mineral salt called Pansalt. Pansalt’s composition is: NaCl 56%, KCl 28%, MgSO4.7H2O 12%, I-lysine-HCl 2%, anticaking agents 2% (IMI Life Products, 2006). By 2002 the program has achieved a significant 3g/day NaCl reduction from 12 to 9g/day (Laatikainen et al., 2006; He & MacGregor, 2008).

The significance of the success of using Pansalt in manufactured food products has sparked an interest in the development and use of salt substitutes. Salt substitutes, are compounds or ingredients that allow for the partial replacement of salt without affecting saltiness of products. There are many different types of substitutes used within the food industry. The most common types are; alternative minerals such potassium chloride, amino acids like arginine, “salty” peptides and organic acids (Dotsch et al., 2009). Other types of salt flavour enhancers are Hydrolysed Vegetable Proteins (HVP), yeast extracts and mono-sodium glutamate (MSG) (Brandsma, 2006). Arguably salt taste is the most important function of NaCl since our innate liking for salt taste in foods has an important role in food choice and acceptance.

7.0 Concerns for food industry for sodium reduction

The food industry is already responding to the need for sodium reduction with 3,000 global low salt food and drink product launches in 2009, double that of 2006 (Katz & Williams, 2010). This underestimates the actual number of products as manufacturers will not label their products as low salt due to possible consumer rejection.
7.1 Loss of palatability and consumer acceptance
Taste is one of the most important factors in food choice. Humans have an innate liking for salt taste and as a result, when large reductions in sodium content occurs there is a decline not only in saltiness of the product but also in palatability and consumer acceptance (Beauchamp et al., 1982; Mattes, 1997). This is an issue for the food industry as dramatic changes in product flavour profiles could potentially alienate consumers and encourage them to choose other product brands (Brandsma, 2006; Dotsch et al., 2009). Estimates by the Consensus Action on Salt Health (CASH) show that a 10-25% reduction in sodium is undetectable by humans senses (Consensus Action on Salt and Health, 2006). This estimate is supported by an Australian study which demonstrated that consumers were not able to detect gradual changes in sodium of up to a 25% in white bread (Girgis et al., 2003). However, with a continual decline of sodium from products it is inevitable that a point will be reached where a difference in flavour profile will be detectable by consumers. Therefore, to achieve large sodium reductions in foods, an approach is required where the salt taste elicited by sodium can be replaced so that the consumer acceptance is not negatively affected (Dotsch et al., 2009).

7.2 Other functions of sodium
There are other functions of sodium in food including binding, flavour enhancement, stabilisation and preservation (Lynch et al., 2009; Taormina, 2010). While it is thought that sodium reduction in foods will affect the functionality of products, evidence presented by Lynch et al demonstrated that reducing sodium level from 1.2% to 0.6% or 0.3% did not significantly affect the functional properties of bread. The only significant difference discovered was the taste qualities between the breads. Overall these results indicate that the production of a lower level salt is technically feasible (Lynch et al., 2009). A number of anecdotal case studies from industry were reported by the New York Times, where qualities such as texture, colour, taste and flavor were negatively affected in various foods (Moss, 2010). It was reported that the food industry was not challenging the Institute of Medicine recommendations on the link between sodium consumption and hypertension, rather that decreasing sodium would increase food prices and also the level of sugars in foods (Moss, 2010).
8.0 Potassium salts as potential sodium substitutes

Although sodium and lithium are the only two cations which produce a true salt taste, potassium also elicits a salt-like taste. Potassium chloride is currently the most commonly used material to replace sodium in foods (Dotsch et al., 2009). In addition to producing a salt-like taste, potassium chloride also elicits a bitter/metallic taste (Van der Klaauw & Smith, 1995). This is thought to occur via the non-sodium specific channel of taste receptor cells (Chandrashekar et al., 2010). When potassium chloride is used in high concentrations the bitter/metallic taste dominates over the salty taste, often causing foods to become unpalatable, thus limiting the utility of potassium chloride as a salt substitute (Ainsworth & Plunkett, 2007).

Studies have been conducted on the acceptability and liking of bread products containing potassium chloride. In a partial substitution study replacing sodium chloride with potassium chloride in white breads found that a 50% substitution of sodium chloride with potassium chloride was considered to have an unpleasant flavour and aftertaste (Braschi et al., 2009). The unpleasant taste associated with high potassium chloride levels is supported by Guy (1986) and Salovaara (1986) who both demonstrated that breads containing potassium chloride at levels of 0.36g and 0.29g/100g respectively were deemed unpalatable by consumers (Salovaara, 1982; Guy, 1986).

These studies indicate that a salt substitute containing high concentrations of potassium will be unpalatable in foods, therefore methods of masking the bitter/metallic tastes associated with the use of potassium salts needs to be found. There have been advances in technologies to reduce any off-flavors elicited by potassium salts and modified potassium chloride salts are currently available in the market place. For example, Rao et al. reported the sensory and functional characteristics of a modified potassium chloride in potato chips, French fries and ham luncheon meat. Results showed replacement of 1/3rd of sodium using a modified potassium chloride without any significant difference in sensory or functional properties of the foods (Rao et al., 2010). Such results are encouraging because by increasing the utility of potassium-salts in foods it is likely that the concentration of potassium in processed foods will increase. Due to a high consumption of processed foods the dietary intake of potassium will potentially increase, which is associated with many significant health benefits such as reduced blood pressure and stroke risk.
9.0 Summary

In summary, excess sodium and insufficient potassium intakes are a major health concern in the developed world as it plays a role in the manifestation of hypertension, stroke and cardiovascular disease (Intersalt Cooperative Research Group, 1988; Bazzano et al., 2001; Strazzullo et al., 2009). Processed foods provide in excess of 75% of sodium in the diet (James et al., 1987) and thus the role of the food industry in a sodium reduction strategy is vital (World Health Organisation, 2006). However, decreasing the sodium content of products will also decrease salty taste and affect palatability and consumer acceptance (Mattes, 1997) and many within the food industry are resistant to major change as recommended in the Institute of Medicine report. If sodium is reduced in food products there is a need to maintain saltiness and consumer appeal of those products and the use of salt substitutes such as potassium-salts could allow for greater sodium reductions without any perceived difference in taste properties.
REFERENCES


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