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Salt reduction strategies in foods

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Abstract

Excessive consumption of dietary salt is the leading cause of cardiovascular disease and hypertension. The average salt intake is approximately twice more than the recommended daily allowance. Given the harmful effects of overconsumption of salt, the dietary concern about salt consumption has encouraged the WHO, along with many international and national health agencies to urged food industries to lower their salt use. Several studies have focused on the formulation of low salt food products. However, due to the crucial functions provided by salt (flavour, texture and shelf-life) salt reduction strategies must be carefully considered. This review highlights numerous approaches for salt reduction in foods which include the use of salt enhancers, salt replacers and bitterness inhibitors and plant based seasonings.

Keywords: Sodium chloride, salt replacers, salt enhancers, salt reduction

Introduction

Salt (sodium chloride, NaCl) is a unique food ingredient that is used extensively in food preparation and processing. Historically, salt has been used to preserve food and contributes to the sensorial characteristic flavour and acceptability of a wide variety of foods. Although salt is essential in our diet, extensive use in processed foods has been a cause of concern. Changing consumer lifestyles and easy accessibility of highly processed and convenience foods have led to increased consumption of salt. (World Health Organization, 2014) ^[126].

Salt consists of 40% sodium and 60% chloride by weight. It is the increased consumption of dietary sodium which is a leading cause of cardiovascular disease (CVD) and hypertension (Wardener and MacGregor, 2002) ^[121]. The relationship between high salt intake and high blood pressure is supported by many observational and experimental studies (INTERSALT, 1988; Ito *et al.* 2016, Ware *et al.* 2017) ^[55, 56, 122]. The DASH (Dietary Approaches to Stop Hypertension) study demonstrated that salt reduction lowers blood pressure in both hypertensive and normotensive individuals, and there is a dose-response to salt reduction (Aburto *et al.* 2013) ^[2].

Globally, the average daily intake of salt is more than twice the recommended dose (Zandstra *et al.* 2016) ^[128]. Salt intake in many countries is between 9 and 12g/day (INTERSALT 1988; Henderson *et al.* 2003, Vedanthan *et al.* 2017) ^[55, 51, 120]. The current World Health Organization recommendations for adults are to reduce salt intake to 5 g/day or less (WHO 2003) ^[123]. It proposes to reduce the sodium intake to less than 2 g/d in adults (WHO 2012). In 2013, member states of the United Nations established a target to reduce the average population salt intake by 30% by 2025 (WHO 2012).

However, reducing the salt intake of consumers will be a difficult task, and will require multi-pronged strategies, one of them will include consumer behavioural change through education. Different approaches have been used to limit sodium and reduce salt in foods, including the use of salt alternatives to control microbial safety (Gyawali & Ibrahim 2014; Wilailux *et al.* 2020) ^[48, 120], salt replacers (Cerrato Rodriguez *et al.*, 2017; Torrico & Prinyawiwatkul, 2017; Pujols *et al.*, 2019) and salt enhancers (Bonorden *et al.*, 2003) ^[18]. Besides, adoption of technological approach of gradual salt reduction, with delivering salt perception at lower salt content. The reformulation of processed foods is the most cost-effective strategy known to reduce dietary sodium intake at the population level (Downs *et al.*, 2015) ^[33].

Function of salt in food

Salt serves several functions in foods. It influences the structure of the food; it plays an antimicrobial role and it contributes to the overall flavour of the food.

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The most important function of salt is as a preservative in food by lowering the water activity and preventing the growth of microbes (Kurlanski, 2002) [93]. Salt not only contributes its own taste to foods, but also works as a flavour enhancer. In addition, salt has the ability to reduce the perception of bitter or astringent compounds present in foods. Besides, salt has specific processing functions in different food categories. In bakery, salt has important effects on gluten, non-emulsified sauces, and flavour modification.

Strategies for reducing salt in food products

Salt serves several functions in foods. It influences the structure of the food; it plays an antimicrobial role and it contributes to the overall flavour of the food.

In order to ensure shelf stability of the food products, hurdle technologies to prevent the growth of microorganisms could be used for delivery of safe food products. These include use of low temperature storage, reduction of water activity (a_w), reduction of pH, modification of oxidation/reduction (E_h), addition of competitive microorganisms and addition of preservatives (Marechal *et al.*, 1999) [74]. By using several different means of inhibition, it is possible to apply each individual hurdle in a reduced intensity and result in food products that are safe, have adequate shelf-life and may be more acceptable to consumers.

i. Natural antimicrobials

The use of natural antimicrobials which assist in food preservation has been recently drawing a lot of attention as an alternative to chemical preservatives traditionally used as antimicrobial agents. Several natural food ingredients which have been customarily used to provide flavour are being used to control microbial growth. Vegetable extracts, mustard, onion, garlic, horseradish and a range of other herbs and spice ingredients including extracts and essential oils from the plants have been shown to inhibit the growth of a range of microorganisms. The active components found in herbs and spices (e.g., thymol from thyme and oregano, cinnamaldehyde from cinnamon, and eugenol from clove) have been shown to have a wide spectrum of antimicrobial activity (Martini *et al.*, 1996; Friedman *et al.*, 2000; Lambert *et al.*, 2001; Gyawali & Ibrahim 2014) [75, 38, 66, 48]. Natural antimicrobials from animal sources include lactoferrin, lysozyme, ovotransferrin and chitosan (Gyawali & Ibrahim 2014) [48].

ii. Organic acids

Organic acids naturally present in many fruits and vegetables such as acetic, citric, malic, tartaric and lactic have been widely used to maintain microbial stability in low pH foods such as fruit juices, beverages, wines, pickled vegetables, mayonnaise, and salad dressings (Pilkington and Rose 1988; Sofos and Busta 1981; Restaino *et al.*, 1982; Seymour, 1998). Spoilage of such foods is most often caused by yeasts, moulds and lactic acid bacteria, as environmental conditions in these foods generally inhibit the growth of bacteria (Beuchat, 1982). The choice of acid will depend on the desired flavour in the final product. Acetic acid is the most antimicrobial of the organic acids but has a strong vinegary odour and taste. Tomato-based products naturally contain citric acid and thus it is most often added to further reduce the pH. Reduced pH works well with salt as a preservation system. Choosing the right level of each factor is critical for product safety and is best done using predictive models or challenge tests.

iii. Salt replacers

Sodium or potassium lactate have been investigated as an alternative to salt (Price 1997) [97]. Sodium lactate works in a similar way as salt, it lowers the a_w of the product but also at lower pH values the acid molecules are undissociated and the lactic acid is able to diffuse across the bacterial membranes and cause further inhibition than that seen by reduced a_w alone. Moreover, comparatively, lower concentrations of sodium lactate are required to prevent growth compared to sodium chloride (salt). This could be possibly because lactates have a greater effect on reducing the a_w of a food than salt i.e. 3% sodium lactate will achieve a lower water activity than 3% sodium chloride (Houtsma *et al.*, 1996). Moreover, the influence of salt to overall flavour can be compensated by the addition of herbs and spices, as well as ingredients such as lemon, onion/garlic, vinegar or other organic acids.

Salt Alternatives from plant-based seasonings

Plant based seasonings such as herbs, spices, dietary plants and their blends have been proposed as an alternative to salt, salt enhancers and salt replacers in low sodium diet and are presently in continuous development (Ashraf *et al.* 2013; Bogdanski *et al.*, 2012; Sengsuk *et al.* 2016) [10, 17, 104]. These seasonings have compounds such as allicin (garlic), gingerol (ginger), capsaicin (pepper), piperine, isopiperine, isoclavine, peperamine and peperolein A and B (black pepper), which gives salty flavor to the food or mask the absence of salt in low salt foods (Szallasi *et al.* 2007) [111]. Besides imparting salty flavour, it has been reported to promote microbial stability, anti-inflammatory, antioxidants and act as vasodilators. Thus, have a preventive action against hypertension (Ashraf *et al.* 2013; Al Disi *et al.* 2016) [10, 3]. Individuals with restricted sodium in their diet programs tend to increase the utilization of plant-derived seasonings to decrease consumption of sodium salt (Land *et al.*, 2016; Taladrid *et al.* 2020) [67].

Garlic

The use of garlic has been suggested as a good alternative to reduce or replace salt by many studies conducted in variety of foods. Nugrahani & Afifah (2016) [87] reported the use of crushed garlic allowed reduction in salt (upto 0.25%) in rice porridge with good acceptable score. In other studies conducted by Horita *et al.* (2016) [53], garlic extract addition as NaCl full replacer in frankfurters has shown a good acceptance by 50% of consumers. Besides, garlic has fascinated state-of-the-art medication due to its role in protection against cardiovascular and respiratory diseases and in lowering hypertension. This is due to presence of quercetin and sulphur containing compounds like γ -glutamyl cysteines and allicin (Bi, Lim, & Henry, 2017; Otunola & Afolayan, 2015; Ried, Frank, & Stocks, 2010) [15, 90, 99].

Lamiaceae family

The Lamiaceae or Labiatae are family of flowering plants commonly known as the mint or deadnettle and includes oregano, rosemary and basil which have also been suggested as a good alternative to reduce or replace salt. These aromatic plants are rich in flavonoids (flavonones, flavones, flavonoids), phenolic acids (hydroxycinnamic acid derivatives) and terpenes (Kaefer & Milner, 2008). In a study conducted by Villela *et al.* (2014) on a preference test, incorporation of oregano into bread resulted in change of

preferences from medium (2%) to low (1.5%) salt concentration. Mitchell *et al.* (2013b) [78] conducted a comparative study between a standard salted vegetable soup and another soup with 48% salt reduction in which rosemary was added; no differences were found in acceptability scores assessed using 9-points hedonic scales.

Herb blends

Herbs are widely used by different cultures in curries (turmeric, coriander, or cumin), Italian dishes (basil, oregano, thyme) or Provence mixes (lavender, fennel, basil, and thyme). Based on acceptance test with 60 consumers, Mitchell *et al.* (2013) [78] reported that herb blends could reduce the use of salt in reduced-salt chilled ready-meals by 40–56%. Low salt margarine was developed to reduce sodium by 50–75% using two blends of herbs and results in no loss of acceptability scores (Lopes *et al.* 2014) [28]. In another study by Ghawi *et al.* (2014) [41] with 148 consumers for five consecutive days, they observed a significant enhancement in the overall liking and the liking flavour of tomato soup with added herb blends (oregano, bay leaves, garlic and black pepper).

Saffron

Saffron is a spice that has been used for more than 4000 years as a remedy in various diseases including hypertension (Srivastava *et al.* 2010) [108]. Licón *et al.* (2012) [72] observed less salt content ($1.77 \pm 0.09\%$) in the cheese prepared from milk with added saffron than control cheese ($2.13 \pm 0.27\%$ salt). Few studies claimed that saffron have beneficial effects in management of blood pressure (Modagheh *et al.* 2008; Nasiri *et al.* 2015) [79, 86].

Hot spices

Hot spices such as chilli and black pepper are known to alter the experience of the basic tastes. Reinbach *et al.* (2010) [98] reported a decrease in desire for salty foods with the addition of hot spices such as chili pepper, fresh ginger, mustard, ground horseradish and wasabi to rice or salad. Similar results were reported by Andersen *et al.* (2017) [6] on adding cayenne to tomato soup. Narukawa *et al.* (2011) [85] conducted a sensory analysis with 27 panellists on effect of adding capsaicin to a 75 mM salt solution. The result indicates that a stronger salt taste was observed when the capsaicin was added to the solution, indicating that capsaicin have effect on the salt perception in humans.

Salt Enhancers

Salt enhancers are substances that do not have any significant saltiness itself, but increases the perception of saltiness when used in combination with NaCl. Numerous compositions have been formulated in which sodium has been partially replaced by other substances such as other mineral salts and amino acids, which are reported to enhance the salty taste of sodium chloride. At present salt enhancers are not widely used in thermally processed food products (Bonorden *et al.*, 2003) [18]. The distinction between saltiness enhancers and salt replacers is often blurred, and compounds classified as enhancers can often have a salty character.

i. Glycine and glycine monoethyl ester

Glycine has been reported to be used in several reduced salt products (Fellendor *et al.* 2018) [36]. It provides a combined function of a salt enhancer together with reducing water

activity in various types of sausages. (Gelabert *et al.*, 2003; Gou *et al.*, 1996; Wilailux *et al.* 2020) [40, 44, 124]. Similarly, Kuramitsu *et al.* (1997) [63] and Segawa *et al.* (1995) [102] have investigated the use of glycine ester in soy sauce. The addition of glycine to sausages at 20% produces a slight reduction of salty taste. Furthermore, glycine ester at higher concentrations when added to soy sauce elicits adverse taste characteristics of sour/acid like, indicating that it should be used at low concentrations to provide a salty taste.

ii. L-lysine and L-arginine

The amino acids L-lysine and L-arginine are used in many commercially available salt enhancers. L-lysine is prepared by the fermentation of corn starch which gives a salty and an astringent response (like horse radish). These amino acids have been used in combination with ornithine, citric acid, succinic acid, potassium chloride, and ammonium chloride. Guerrero *et al.* (1995) [47] has described a salt-taste-enhancing composition, which is prepared by enzymically hydrolysing a protein in the absence of added sodium and which can be used in a wide variety of foods and beverages. The resulting hydrolysate contains free lysine and free arginine which is used along with ammonium salt. This composition when dehydrated and added to a food or beverage containing a reduced amount of sodium chloride, the salty taste is enhanced and, in some cases, the flavour of the food or beverage is enhanced.

iii. Lactates

Potassium, sodium and calcium lactate have been reported to be used as saltiness enhancers. (Devlieghere *et al.* 2009) [31] In the meat and poultry industries potassium and sodium lactates are not only used as antimicrobial agents but also provide saltiness (Fellendorf *et al.* 2018) [36]. However, their application for this purpose is not widespread. Calcium is usually added to foods as a salt of organic anions such as lactate (Lawless *et al.*, 2003) [68, 69] but calcium lactate has pronounced sourness. Minute quantities of volatile lactic acid produced by interaction of the lactate with water are easily detectable in a neutral carrier (Tordoff, 1996) [115].

iv. Mycoscent

Mycoscent is obtained from mycoprotein and marketed as Quorn. It is a natural source of ribonucleotides and glutamic acid, with the ability to impart a salty taste without the addition of salt and provides flavour enhancing properties too. It can be used to provide a 50% sodium reduction in biscuits and snack foods and 25% sodium reduction in savoury dishes as it has a synergistic effect with dairy and savoury flavours. It is suggested for use as a salt enhancer or substitute and is used to deliver a tender, cooked taste in meat products (Mycoscent, 2005) [83].

v. Trehalose

Trehalose is a non-reducing disaccharide formed from two glucose units joined by α -1,1 bond. It is used as a saltiness enhancer to sodium chloride without imparting any unpleasant after taste or flavour to food products. It is used by European Commission as a novel food ingredient (EC 2001) [35] It has been used as a flavour enhancer in ready to eat meat and poultry products. Moreover, it has been used to effectively reduce or mask the taste of bitterness, metallic and astringency in foods. (Cargill (2018) [24].

vi. L-ornithine

Tuong *et al.* 1990^[116] have reported that several dipeptides derived from L-ornithine increase saltiness. L-ornithyl taurine monohydrochloride and ornithyl- β -alanine monohydrochloride have demonstrated strongest salty taste without any bitter after taste. According to Kuramitsu (2004)^[62] a 60% reduction in salt can be accomplished in soy sauce by employing Ornithyl taurine hydrochloride. Similarly, Nakamura *et al.* (1996) also reported that L-ornithyl taurine monohydrochloride enhances perception of saltiness, but with an accompanying sourness.

vii. O-aminoacyl sugars

Tamura *et al.*, 1989; 1993^[114, 113] have reported that Ornithyl- β -alanine (OBA) besides providing a salty taste also functions as a saltiness enhancer with sodium chloride. It can be used to produce low- salt products by partial replacement of NaCl or its substitutes, especially for people with hypertension, diabetes and heart diseases (Kuramitsu 2004; Seki *et al.* 1990)^[62, 103]. However, this is an extremely expensive ingredient to synthesise, and Tamura *et al.* (1993)^[113] also points out that a saltiness 20 times that of sodium chloride is needed to avoid excessive intake of amino acids or peptides.

viii. Glutamates

Glutamates are among the most common amino acids present in many proteins, peptides and tissues. When they are bound to a protein molecule, they are tasteless. However, protein hydrolysis during fermentation, aging, ripening and heat processing will liberate free glutamate (Yoshida, 1998)^[127]. The free glutamates liberated possess unique taste referred to as a fifth taste or umami that is different from any other basic taste (Jinap *et al.* 2010)^[57].

Monosodium glutamate (MSG) is a sodium salt of glutamic Acid which has long been used in several Asian cuisines for its umami taste. MSG does not have a pleasant taste by itself (Halpern, 2000)^[50], but at low concentrations it can enhance the taste of other compounds. It has been often suggested that MSG could be used as a means of reducing sodium chloride

levels while maintaining acceptable flavour (Okiyama and Beauchamp, 1998)^[88]. MSG enhances salivary secretion, enhances appetite and increase food palatability, and interferes with carbohydrate metabolism. The pleasantness of reduced-salt soups could be improved by supplementation of MSG (Roininen *et al.* 1996)^[100]. MSG can be used as a salt replacer in salt reduced potato chips (up to 30%) with no or minimal loss of acceptability for 80-90% of the panellists (Kongstad & Giacalone 2020)^[60].

In some preclinical studies, MSG has been reported to be associated with cardiotoxicity, hepatotoxicity, neurotoxicity, low-grade inflammation, metabolic disarray, and premalignant alterations, asthma, migraine headache and Chinese Restaurant Syndrome (CRS) (Jinap *et al.* 2010; Zanfirescu *et al.* 2019)^[57, 129]. In spite of this, Zanfirescu *et al.* 2019^[129] reported a number of methodological flaws, and infer that these studies have inadequate relevance for extrapolation to dietary human intake of MSG risk exposure.

A small amount of research has been done on the flavour characteristics of calcium diglutamate (CDG), sometimes also referred to as calcium glutamate (Prescott, 2001)^[96]. Being free of sodium, it could potentially achieve equivalent taste characteristics at lower sodium concentrations than MSG (Bellisle *et al.*, 1992)^[13]. However, little research has been published on the taste characteristics of CDG in relation to foods and it appears to be little used as an additive (Ball *et al.*, 2002).

ix. Alapyridaine

Alapyridaine (N-(1-Carboxyethyl)-6-hydroxymethyl-pyridinium-3-ol) is a compound discovered in heated glucose/alanine solutions (Frank *et al.*, 2001)^[37]. Alapyridaine is formed in thermally processed beef broth and is found to be tasteless on its own. The presence of alapyridaine was found to enhance sweetness, umami tastes, and influences salt perception (Ottinger and Hofmann, 2003). Currently, however, alapyridaine is not commercially available.

Table 1: Compilation of sensory studies on the use of salt replacers and enhancers in low salt foods

Salt replacers	% salt reduction	Food product	Test type	Number and type of panelists	References
Potassium chloride	20–30%	White bread	A single-blind organoleptic evaluation	41 untrained	Braschi <i>et al.</i> 2009 ^[20]
Potassium chloride	30%	Pizza crust	Sensory tests	18 trained assessors	Mueller <i>et al.</i> (2016) ^[82]
KCl, l-lysine hydrochloride and l-glutamic acid	40%	Tomato soup	Sensory profiling analysis	8 trained	Akgün <i>et al.</i> (2019)
Potassium chloride	50%	Cooked hams	A consumer sensory panel	69	Frye <i>et al.</i> (1986) ^[39]
Modified KCl salt, co-crystallised with 50-ribonucleotides IMP and GMP	75%	Pork sausage patties	Sensory tests	71	Pasin <i>et al.</i> (1989) ^[91]
Glycine and potassium lactate	40%	Fermented sausages	10 point hedonic test	5 trained assessors	Gou <i>et al.</i> (1996) ^[44]
Mycoscent	50%	Biscuits and snack	Sensory tests		Mycoscent. (2005) ^[83]
Mycoscent	25%	Savoury dishes	Sensory tests		Mycoscent. (2005) ^[83]
Potassium lactate and sodium diacetate	40%	Meat products	Sensory evaluation	4 trained	Devlieghere <i>et al.</i> (2009) ^[31]
KCl and glycine	25%	Frankfurters	Acceptability tests	100 untrained	Wilailux <i>et al.</i> (2019)

Salt replacement

Salt replacement involves partial replacement of sodium cation by either organic or inorganic salts that elicit saltiness but do not contain sodium such as potassium, ammonium,

magnesium, calcium and lithium and by anions such as phosphate and glutamates (Sinopoli & Lawless, 2012; Van Buren & Newson, 2016)^[106]. Since, NaCl is the only salt that provides the classic salty taste (Kilcast & Angus, 2007)^[7].

Optimizing the correct amount of each of these salts used is the key to control biochemical reactions and avoid sensory alterations and undesirable changes (Wilailux *et al.* 2020) [124]. Extensive efforts are being made to replace salt with combination of other salts and/or new materials that can deliver a clean salty taste, without any after taste or bitterness. However, these salt reduction strategies are likely to be expensive for the food manufacturer, as it will require the incorporation of novel ingredients which will be costly.

Potassium chloride

Potassium chloride (KCl) is the most commonly used salt replacer (Busch *et al.*, 2013; van Buren *et al.*, 2016) [23, 117]. It gives salty taste which is a little different from that of NaCl (Wilson *et al.*, 2012) [125]. Besides imparting saltiness, KCl helps to improve the shelf life of foods due to its antimicrobial property comparable to that of NaCl (Bidlas & Lambert, 2008) [16]. Potassium chloride-containing salt substitute lowers blood pressure levels and risk of hypertension (Aaron & Sanders (2013) [1]; Kilcast & Angus, 2007 [7]; van Buren *et al.*, 2016) [117], however its potential to cause bitter/chemical/metallic taste and aftertaste has been of concern. Replacement of a fraction of the sodium chloride with potassium chloride is currently practiced for sodium reduction. 30% replacement of sodium chloride by potassium chloride did not significantly affect consumers' sensory and hedonic perception in many food products and is generally considered to be feasible (Antunez *et al.* 2018) [8]. 50% replacement of sodium is feasible only for certain food products.

Results from previous studies conducted on replacing NaCl with KCl in a variety of food products such as cheddar cheese, brown and white bread, sausages, dry-cured ham, rabbit meat, frankfurter sausages, pizza crust, and Mina fresh cheese (Charlton *et al.* 2007; Braschi *et al.* 2009; Gomes *et al.*, 2011; Armenteros *et al.* 2012; Grummer *et al.* 2013; Horita *et al.* 2014; Paulsen *et al.*, 2014; Soglia *et al.*, 2014; Bernklau *et al.*, 2017) [25, 20, 43, 9, 46, 52, 92, 107, 14] revealed that upto 20% to 50% replacement of sodium with potassium is possible and acceptability differs depending on the food product, which suggests that the recommended replacement dose should be made on a product specific basis.

Nevertheless, masking the undesirable taste associated with potassium chloride remains a challenge. In the past years, efforts have been made to mask the tastes associated with Potassium chloride with MSG, ammonium chloride, magnesium sulphate and amino acids. KCl is often combined with flavour enhancers, bitter blockers or sweeteners (Ley *et al.* 2008) [70].

Other potassium salts

Sodium replacement is also accomplished using other potassium salts such as potassium sulphate and potassium glutamate either alone, or in combination with potassium chloride (Varnam and Sutherland, 1995) [119]. Potassium sulphate is an inorganic compound which has potassium and sulphur and has significant scores of the four the basic tastes (Shallenberger, 1993) [105]. Potassium lactate, can be used as suitable material for NaCl replacement while retaining the perceived saltiness and bacteriostatic control. Potassium lactate can be mixed with substances that block bitterness like glycine to achieve upto 40% NaCl replacement in fermented sausages without any effect on sensory acceptability (Gou *et al.* 1996; Angus *et al.* 2005) [44, 7]. In addition, it has a positive effect on water holding capacity which may result in a higher

cook yield and an improved texture for the cooked product (Stekelenburg, 2003) [109].

Calcium chloride

The taste of calcium chloride is both bitter and sweet and depends on its concentration. At 1mM, it is described as bitter, sour and sweet while at 100 mM as bitter, salty and sour (Klaauw and Smith, 1995; Tordoff, 1996; Lawless *et al.*, 2003) [115, 68, 69]. At high doses, it may be metallic taste, astringent and cause irritation (Lawless *et al.*, 2003) [68, 69]. When combined with sodium chloride, the salty perception is enhanced whereas, other tastes, like bitterness is suppressed. These effects have the potential of enhancing the palatability of calcium salts as fortifying agents (Shallenberger, 1993; Lawless *et al.*, 2003) [105, 68, 69]. Bassett *et al.* (2014) [11] reported that low sodium bread containing 50% less NaCl have similar textural, organoleptic and colour attributes to that of control bread when made with CaCl₂.

Magnesium sulphate

Magnesium sulphate is perceived as both bitter and salty in taste, which is reported to vary depending on its concentration (Delwiche *et al.*, 1999; Lawless *et al.*, 2003) [68, 69]. At low levels it is associated with a salty taste compared to high levels where it is perceived as being bitter (Shallenberger, 1993) [105]. Therefore, it may have the prospect of being used as a salt replacer. It has also been suggested that the addition of magnesium sulphate into salt mixtures has potential health benefits, such as reducing blood pressure. It is often used in food as an additive to adjust the pH. Their applications are limited in salt replacement due to their unpleasant flavour.

Bitterness inhibitors

Bitter and metallic flavours associated with potassium chloride have limitations in practical applications as salt replacers (Cruz *et al.*, 2011; Grummer *et al.* 2012; Khetra *et al.* 2018) [26, 46, 58]. Masking the perceived bitterness associated with salt replacers has been investigated using a number of compounds (Haga *et al.*, 1984; Kurihara *et al.*, 1994; Khetra *et al.* 2018 [58]; Grummer *et al.* (2012) [46]. Several compounds have been reported to reduce bitterness including Adenosine-5'-monophosphate, 2,4-Dihydroxybenzoic acid, Lactose, Sodium gluconate, l-lysine, l-arginine and Trehalose (Beeren *et al.* 2019) [12]. However, bitterness inhibitor suitable for general use has not been identified so far.

Adenosine-5' -monophosphate (AMP) is the most excessively used among bitterness inhibitors (McGregor, 2004) [76]. It improves the taste of mixtures such as NaCl and KCl. Food ingredients that have umami taste can also be used to mask the bitter flavour of low sodium products and to increase the perception of saltiness (Mojet *et al.*, 2004) [80]. These compounds contain high amount of glutamates like soy sauce, yeast extracts, monosodium glutamate (MSG) and hydrolyzed vegetable protein (Brandsma, 2006; Dotsch *et al.*, 2009; Kremer *et al.*, 2009) [19, 32, 61]. Similarly, Khetra *et al.* (2018) [58] use hydrolysed vegetable protein and adenosine-50-monophosphate as bitterness inhibitors of low sodium cheddar cheese in which 75% of NaCl is replaced with KCl. The bitterness inhibitors resulted in significant improvement in the flavor, saltiness, and bitterness characteristics compared to control.

Sugar is also often for masking bitterness in low sodium food products. In 2014 the American Heart Association reported a 40–50% dropped in snack sales when manufacturers reduced sodium. Thus, food and beverage companies added

sweeteners to compensate for this sodium reduction. The use of sweeteners has been previously demonstrated to be effective in reducing bitterness. When used at low concentrations, in combination with other compounds, the perceived sweet aftertaste is removed, while masking the perceived bitterness. Sucrose is commercially the most commonly used sweetener, but other sweeteners have been investigated, and in view of the long persistence of bitterness that can occur, the use of intense sweeteners such as thaumatin also characterised by long persistence, has been investigated exhaustively.

Thaumatococcus daniellii (*Benth.*) is used for its ability to mask bitterness both in the taste and aftertaste of a product. In many food applications, thaumatin can be used at levels below 10 ppm providing the best flavour modification or even flavouring.

2,4-dihydroxybenzoic acid (DHB) and its salts have been identified as potential bitter inhibitors which do not affect sweetness. It has also been reported to be effective at eliminating the undesirable metallic aftertaste often associated with saccharin. It has been primarily added to salt mixtures used to season baked potatoes, popcorn and other edibles. Although it has a good taste profile, but it is prone to decarboxylation at low pH (Kurtz and Fuller, 1997) [65].

Compounds that decrease the perception of bitterness

The food industry has always used taste modifying compounds to ameliorate the taste of food products. Some examples include the use of salt and sugar to decrease the perception of bitterness and the use of the nucleotide's inosine

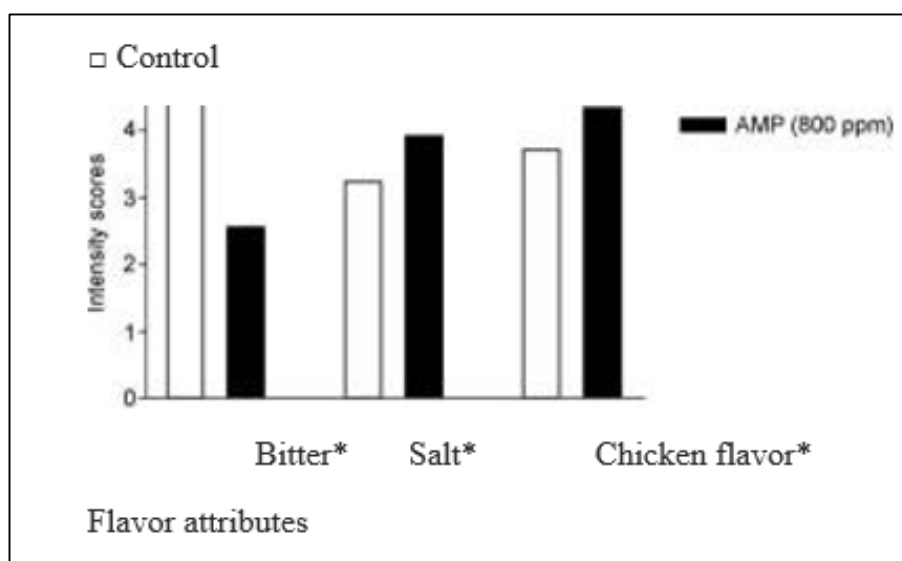
monophosphate and guanosine monophosphate to potentiate the umami taste of monosodium glutamate.

With the characterization of the taste system at the molecular level there are a number of available approaches involving taste modification to reduce the levels of sodium in processed foods. The three approaches suggested are substitution of potassium salts with sodium salts, potentiation of sodium taste, and replacement of sodium with a novel salty tasting molecule.

In addition to potassium chloride, ammonium salts and certain dipeptides and cationic amino acids, such as ornithyl-beta-alanine, lysine-ornithine hydrochloride, arginine and lysine have a salty taste. However, like potassium chloride, the application of these compounds as salt substitutes is limited by bitter taste.

The biopharmaceutical approach to improving taste has facilitated to reduce the salt content of food products. Using an assay that monitors the activation of the taste G protein by bitter tastants, adenosine 5'- monophosphate (AMP) was identified as a compound that reduces taste cell activation by bitter compounds (Ming *et al.*, 1999) [79]. Mouse preference studies confirmed that AMP improved the palatability of bitter solutions and electrophysiological recordings showed a decreased activation of nerve responses by bitter compounds in the presence of AMP.

A chicken broth with reduced-sodium + 1.5% KCl with addition of AMP leads to increased saltiness and umami taste in the soup. This is likely due to two factors, the inherent umami taste of AMP at higher concentrations and the reduction of bitterness leading to the saltiness and umami taste of the soup being more pronounced. (BNF 1994).



* Statistically significant, 95% CI 19 trained panelists
0-8 intensity scale, 8 = highest intensity

Fig 1: AMP reduces the bitterness of potassium chloride supplemented low sodium chicken broth and increases the saltiness and overall flavour.

Increasing perception of salty taste

Maximum saltiness of topically applied salt is usually not achieved as the largest salt crystals do not dissolve fast enough to reach the sodium receptors in the mouth before swallowing. It seems reasonable to hypothesise that the efficiency of a given amount of salt could be increased if the ions comprising salt could reach the receptors more quickly. Sodium chloride elicits a salty taste only when in solution. A rapid dissolution rate could intensify saltiness in some foods and thus reduce the levels required. The dissolution rate of

sodium chloride in the mouth is partly determined by the exposed surface area, is a function of crystal size and crystal form.

Smaller crystal sizes and a low bulk density results in a large surface area due to a long flat shape, flakes have a lower bulk density, and thus a faster rate of dissolution. Crystal shape and crystal density also influences the rate of dissolution, dendritic salt has voids throughout the crystal, thus drastically increasing exposed surface area, which again increases the dissolution rate (Bravieri, 1983) [21]. Differences in salt crystal

form and resultant differences in salt dissolution rate seems to be the main reasons for the perceived higher quality of many sea salts in comparison to common table salt, which is inevitably in a cubic crystal form.

Conclusions and future trends

Saltiness is an important sensory attribute of many foods, and salt itself contributes even more to the characteristic flavour of many food types. Though an adequate dietary salt intake is vital to health, the intake has become too high, with substantial health risks. Changing the salt intake of a consumer population that has adapted to a high salt diet will not be easy, and will entail several strategies, one of the most important of which will be consumer education. Besides, a strategy with a more technological approach toward delivering salt perception at lower salt content. Considerable efforts are now being made to utilise the recent progress in understanding the mechanisms underlying taste perception to find new materials that can deliver salty taste or suppress unwanted tastes such as bitterness. However, most options are likely to have cost implications for the food manufacturer, as any strategy involving enhancement or replacement will require the incorporation of a more expensive ingredient. Against this, though, are the substantial benefits to health that will accrue from an innovative approach.

In fact, although a number of approaches to reducing salt content are available, they face challenges due to taste, safety or cost of production that means relatively few salt products are currently on the market, particularly when compared to the plethora of low-sugar and low-fat products that are available, where good tasting alternatives have been identified.

Traditionally, herbs and spices have been used as salt substitutes, including black pepper, curry powder, garlic, onion, tarragon, basil, ginger, cumin, dill seed and coriander. Lemon and vinegar can also be used as salt substitutes. Enhancers of salty taste include peptides from a variety of hydrolyzed sources including collagen, soybean, wheat, egg white and milk, and the sweeteners thaumatin and trehalose. In addition, alkylidienamides have been shown to potentiate salty taste and in reducing sodium content in food ingredients.

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