SENSORY PROPERTIES, CONSUMER PERCEPTION, AND ANALYTICAL ASSESSMENT OF REFORMULATED REDUCED SODIUM READY TO EAT PRODUCTS

By

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SENSORY PROPERTIES, CONSUMER PERCEPTION, AND ANALYTICAL ASSESSMENT OF REFORMULATED REDUCED SODIUM READY TO EAT PRODUCTS

Abstract

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Sodium reduction in ready to eat products is complex but is needed to alleviate the health concerns that accompany overconsumption. Therefore, the overall objective of this research was to understand the sensory properties, consumer perception, and analytical changes of ready to eat products that are reformulated for a reduced sodium content. This research consisted of 4 studies; the first 3 investigated salt reduction strategies of salt mixtures, odor-induced saltiness enhancement (OISE), and processing technique analyzed by sensory evaluation and analytical assessments. The last study investigated a novel method for evaluating consumer acceptance of salt. In study one, an electronic tongue, sensory evaluation, and mixture design methodology were used to evaluate salt solutions and tomato soups prepared with different salt mixtures, including NaCl, KCl, and CaCl₂. Electronic tongue analysis showed a high discrimination index (96%) indicating distinct differences among salt mixtures; strong positive correlations ($R^2 > 0.90$) were found between sensory and electronic tongue data. In
study two, the influence of OISE and storage time were investigated in chicken pasta meals processed by microwave-assisted thermal sterilization (MATS). The addition of herbs allowed for a 50% salt reduction while maintaining the same intensity of saltiness perception and overall meal acceptance. In study three, the combination of OISE and processing technique (fresh, retorted, and MATS) was used to investigate salt reduction in mashed potatoes. The electronic tongue showed a high discrimination index for fresh (89%) and processed (95%) mashed potatoes, indicating its ability to distinguish among them. Sensory results showed the salt level could be reduced by 30% in mashed potatoes while still maintaining salt, flavor, and overall acceptance but with a loss in saltiness intensity perception. The last study showed consumers differed in their affective reactions to a salt solution and tomato soup, and the subsequent translation of these reactions into physical shapes. Information from this study will give product developers a novel method to understand consumer affective responses to salt. Overall, this research has contributed to understanding salt reduction, and demonstrated the influence that product reformulation can have on final product evaluations by sensory panels and analytical assessments.
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CHAPTER I
INTRODUCTION

The current estimated intake of sodium, 4g per day (Powles et al., 2013), versus the recommended intake of sodium, less than 2g per day (WHO, 2007) vary drastically. Overconsumption of sodium is an issue since it leads to many health concerns including increased blood pressure, risk of cardiovascular disease, stroke, renal disease, gastric cancer, and atrial fibrillation (Cook et al., 2007; He & MacGregor, 2009; Strazzullo, D’Elia, Kandala, & Cappuccio, 2009; Suckling, He, & MacGregor, 2010; Tsugane, 2005; Yang et al., 2011; Pääkkö et al., 2018). Furthermore, recent research has demonstrated that sodium intake showed a linear relationship with mortality (He et al., 2018).

The detrimental effects that overconsumption of sodium can have on health suggests that its intake should be reduced. Indeed, salt reduction could be one of the most cost-effective, and in some cases cost-saving, ways of reducing the growing burden of non-communicable diseases (Neal, Yangfeng, & Li, 2007). To this end, a global target of 30% relative reduction in mean population intake of salt by 2025 has been established by the World Health Organization (WHO, 2012).

To effectively reduce sodium intake, one must first identify the major sources of sodium within the diet. The major dietary source of sodium is from common salt or sodium chloride (~90%) (He & MacGregor, 2010), and about 75% of sodium intake in the United States comes from processed foods (Brown, Tzoulaki, Candeias, & Elliott, 2009; Mattes & Donnelly, 1991). Thus, a reduction in sodium in processed foods would help to alleviate some of the overconsumption of sodium in the U.S. Indeed, food
product reformulation has been identified by WHO as one of the key pillars for salt reduction (WHO, 2007). Therefore, the focus of the present research is on sodium reduction strategies in processed foods via different product reformulation techniques.

Salt has many functions in foods including flavor enhancement, masking bitter flavors, impacting texture, and preservation (Doyle & Glass, 2010). With all the unique functions and properties salt contributes to foods, its reduction is complex. Due to this complexity, numerous strategies have been investigated to aid in achieving salt reduction targets (Kilcast & Angus, 2007). To date, most of the studied strategies for salt reduction fall into one of three main principles: cognitive, chemical, or physical mechanisms (Busch, Yong, & Goh, 2013).

Decreasing salt in food generally leads to a decrease in consumer acceptability (Breslin & Beauchamp, 1997). Thus, salt reduction must be approached strategically so as to not result in the loss of consumer acceptability of a product or prompt the addition of extra salt at the table. Jaenke et al. (2016) completed the first systematic review of ~50 studies that investigated salt reduction acceptance of reformulated food products to determine the extent to which salt could be reduced while maintaining consumer acceptability. With reduction by stealth, replacement, or compensation in processed foods, salt could be reduced by approximately 40% in breads and approximately 70% in processed meats without significantly impacting consumer acceptability (Jaenke, Barzi, McMahon, Webster, & Brimblecombe, 2016). However, the results for other products varied and more research is needed on salt reduction strategies.

There are two main alternatives to salt: salt replacers and saltiness enhancers (Durack, Alonso-Gomez, & Wilkinson, 2008). The most widely used salt replacer is
potassium chloride (KCl); however it often contributes a bitter and metallic aftertaste and astringent mouthfeel, thus limiting its applications (Lawless, Rapacki, Horne, & Hayes, 2003). On the other hand, herbs are commonly regarded as salt enhancers (Durack et al., 2008). Additionally, aromas associated with saltiness have been found to elicit an odor induced saltiness enhancement (OISE) in both aqueous solutions and model cheeses. (Lawrence et al., 2011; Lawrence, Salles, Septier, Busch, & Thomas-Danguin, 2009; Nasri, Septier, Beno, Salles, & Thomas-Danguin, 2013).

New opportunities for salt reduction accompany newly developed food processing methods that may enhance saltiness perception. For example, high pressure processing resulted in an increase in saltiness perception in dry-cured ham (Clariana et al., 2011). Another new food processing technology, microwave-assisted thermal sterilization (MATS), has produced foods that taste saltier than their counterparts processed in retorts (Tang, 2015). The difference in perception of saltiness between microwaved processed versus retorted foods was first attributed to reduced salt diffusion; however, it was discovered that salt continues to migrate into the solid food product post-processing (Bornhorst, Tang, & Sablani, 2016). This is important to sensory perception as salt that has diffused into a food is not as readily accessible to the taste receptors compared to the salt on the surface of a food, resulting in a decreased salty taste (Henney, Taylor, & Boon, 2010).

To maintain product quality and retain customer satisfaction, an understanding of salt perception and acceptance is of high importance. Previous work shows that saltiness is accepted at different levels among consumers (Hayes, Sullivan, & Duffy, 2010), varies by food type (Hayes et al., 2010), and that salt reduction strategies are
matrix dependent (Barnett, Diako, & Ross, 2019). Therefore, a thorough understanding of salt perception within the food product undergoing salt reduction is important for salt reduction to be successful.

Currently, objective sensory research reports on salt taste perception and temporality are vast, but the subjective understanding of the salt taste experience is still missing (Obrist et al., 2014). There is an accumulation of studies showing crossmodal relationships between shapes and basic tastes that suggest that shape features of product design, particularly package design, could convey taste information prior to product purchase and potentially influence affective ratings of the product (Velasco, Woods, Petit, Cheok, & Spence, 2016). Allowing participants to have the ability to manipulate a shape to describe their sensory experience with salty taste may be of value to better understand the salt-shape crossmodal relationship and how this information could be used to affect product or package design to convey taste perception.

For salt reduction targets to be reached successfully, more than one salt reduction strategy is needed. Combining strategies, such as OISE and new processing methods for example, may allow for larger salt reductions while maintaining consumer acceptability of the product. Additionally, creating new avenues for describing sensory experiences may allow product developers and sensory scientists a better subjective understanding of salt reduced products.

The overall goal of this research was to understand the sensory properties, consumer perception, and analytical changes of ready to eat products that are reformulated for a reduced sodium content. This goal was researched through the examination of sensory evaluation, electronic tongue analysis, and HS-SPME/GC-MS of
reformulated ready-to-eat products that were reduced in sodium. The central hypothesis of this dissertation was that with product reformulation, sodium reduction can be achieved while maintaining sensory perception and consumer acceptance of the product.

To investigate the central hypothesis, four specific aims were developed. Research aim one (Chapter 3) investigated the application of salt mixtures in a model aqueous system and tomato soup. In both systems, sensory changes and chemical changes were described. The objective of aim one was to determine the relationship between consumer perception and electronic tongue detection of three different salts, currently used in salt reduction strategies, in an aqueous solution and a tomato soup.

Specific research aim two (Chapter 4) studied the influence of product reformulation (addition of herbs), and storage time on the sodium reduction potential in a chicken pasta meal. The primary objective of this study was to determine if the addition of herbs into a microwave-processed reduced salt meal would result in a higher perceived intensity of salt (OISE effect), thus allowing less salt to be added to the meal without a noticeable different in saltiness by consumers. Secondly, this study investigated the influence of storage time on the chicken pasta meals.

In specific aim three (Chapter 5), mashed potatoes, with different flavors and salt contents, were studied to understand the influence of processing (fresh, retort, MATS) on product assessment. This study allowed for the investigation of the potential combination effect of OISE and processing method on salt reduction in reformulated ready to eat mashed potatoes. The objective of this study was to determine the effects of flavor addition, salt variation, and processing method on the consumer perception,
consumer acceptance, electronic tongue evaluation, and volatile analysis of reformulated, ready to eat mashed potatoes.

In specific aim four (Chapter 6), a novel method for evaluating consumer acceptance of salt was investigated. The objective of this study was to understand the crossmodal interaction between salt taste and shape formation, specifically the relationship between consumer affective reactions to a basic salt solution and a tomato soup, and the resulting clay figure molded to describe the sensory experience.

Finally, Chapter 7 summarizes all research findings in the preceding chapters and future directions are proposed. All articles, for chapters 3, 4, 5, and 6, are presented in their original format.
CHAPTER II
LITERATURE REVIEW

HEALTH IMPLICATIONS OF HIGH SODIUM INTAKE

Sodium is an essential mineral responsible for controlling blood pressure, cell water content, and facilitating nerve impulse transition (Mills & Norton, 2013). The physiological requirement for sodium is less than 0.4 g per day (Dahl, Leitl, & Heine, 1972), and for several million years humans ate a diet that contained less than 0.69g per day of sodium based on a 3,000 kcal diet, resulting in mechanisms to conserve sodium within the body (Eaton & Konner, 1985). However, the current estimated intake of sodium versus the recommended intake of sodium vary drastically. The average global daily sodium intake is estimated at 4g per day (Powles et al. 2013) while the WHO recommends a sodium intake of less than 2g per day (WHO 2007). The U.S. recommendation is 2.3g of sodium per day or less (U.S. Department of Health and Human Services and U.S. Department of Agriculture 2015). It has been suggested that these recommendations are not low enough and a further reduction to 1.2g of sodium per day should be the long-term target for population sodium intake worldwide (He and MacGregor 2007). These lower recommendations are based on the health implications of high sodium intake.

Overconsumption of sodium can lead to many health problems including increased blood pressure, risk of cardiovascular disease, stroke, renal disease, gastric cancer, and atrial fibrillation (Cook et al., 2007; He & MacGregor, 2009; Strazzullo, D’Elia, Kandala, & Cappuccio, 2009; Suckling, He, & MacGregor, 2010; Tsugane, 2005;
Yang et al., 2011; Pääkkö et al., 2018). Indeed, high sodium intake has been identified as one of the top two dietary risk factors for global disability-adjusted life years (DALYs) by the Global Burden of Disease (Lim et al., 2012). There is overwhelming evidence for a causal relationship between salt intake and blood pressure with evidence coming from epidemiological studies, migration studies, population-based intervention studies, treatment trials, animal studies, and genetic studies (He & MacGregor, 2007).

A meta-analysis of treatment trails demonstrated that a modest reduction in salt intake had a significant effect on blood pressure in both hypertensive and normal blood pressure individuals (He & MacGregor, 2002). In chimpanzees as salt intake increased from 5, 10, to 15 g per day, their blood pressure continued to increase, and 3 months after supplementation ended their blood pressure returned to baseline level (Denton et al., 1995). Furthermore, recent research has demonstrated that when accurately measured, sodium intake showed a linear relationship with mortality. This study also found that the use of inaccurately estimated sodium changed the relationship and could explain the paradoxical J-shaped findings reported in some cohort studies (He et al., 2018). These studies all point to the detrimental effects that overconsumption of sodium can have on health and suggest its intake should be reduced.

Reducing salt intake to recommended levels can be an effective intervention to reduce the burden of non-communicable diseases. Salt reduction could be one of the most cost-effective, and in some cases cost-saving, ways of reducing the growing burden of non-communicable diseases (Neal et al., 2007). A global target of 30% relative reduction in mean population intake of salt by 2025 has been established (WHO, 2012).
and as of 2014, 83 countries were identified as having salt reduction strategies in place or planned (Webster, Trieu, Dunford, & Hawkes, 2014).

To effectively reduce sodium intake, one must first identify the major sources of sodium within the diet. The major dietary source of sodium is from common salt or sodium chloride (~90%) (He & MacGregor, 2010). Salt and sodium are often used synonymously, but salt is 40% sodium and 60% chloride. Thus, 1 g sodium = 2.5 g salt; 1 g salt = 0.4 g sodium. In this literature review, when salt is mentioned it is referring to sodium chloride (NaCl) unless specified otherwise. About 75% of sodium intake in the United States comes from processed foods (Brown et al., 2009; Mattes & Donnelly, 1991). Thus, a reduction in sodium in processed foods would help alleviate some of the overconsumption of sodium in the U.S. Indeed, food product reformulation has been identified by WHO as one of the key pillars for salt reduction (WHO, 2007). Therefore, the focus of the present research is on sodium reduction strategies in processed foods via different product reformulation techniques.

SALT PERCEPTION AND FUNCTIONALITY WITHIN FOOD

Removing salt from food is associated with many challenges as its presence serves multiple functionalities within products. Salt serves a unique sensory role within food products as a result of the mechanism by which it is perceived. Mouse models indicate that there are two epithelial sodium channels (ENaCs) involved in salt perception (Chandrashekar et al., 2010), an amiloride-sensitive and amiloride-insensitive pathway (Bradbury, 2004; Garcia-Bailo, Toguri, Eny, & El-Sohemy, 2009; McCaughey, 2007; Roper, 2007). The chemical signal produced sends an electrical
signal that travels down afferent nerve fibers to the brain where there is an encoded ‘gustotopic map’ of distinct hot spots for different taste qualities in the gustatory cortex (Chen, Gabitto, Peng, Ryba, & Zuker, 2011). The concentration of salt in products can determine if the salt present will be detected. The salt detection threshold is 0.096g/L (Wise & Breslin, 2013), the salt recognition threshold is 0.83g/L (Wise & Breslin, 2013), and the salt suprathreshold is 2.34 g/L (Pfaffmann, Bartoshuk, & McBurney, 1971).

Additionally, the rate of release of sodium ions impacts perception and depends on structure and composition of the food and on mastication and salivation (Neyraud, Prinz, & Dransfield, 2003). Humans taste salt by diffusion of simple ions from specific inorganic ions (Bradbury, 2004; Roper, 2007) and replacement of common salt with alternative salts can bring challenges as both the sodium and chloride ion are required for activation of the salt receptor and salts with larger anions do not provide much saltiness (Van Der Klaauw & Smith, 1995). Several cations other than Na\(^{+}\), such as NH\(_4\)\(^{+}\), K\(^{+}\), Mg\(^{2+}\), Ca\(^{2+}\), and Li\(^{+}\) can elicit salty taste, but they can also bring with them unwanted sensory changes such as bitterness, sourness, or astringency, rather than a purely salty taste (Keast, 2003; Lawless et al., 2003; Murphy, Cardello, & Brand, 1981; Roper, 2007; Van Der Klaauw & Smith, 1995). Therefore, sodium chloride is the ideal compound for pure saltiness (Kilcast & den Ridder, 2007).

When reducing salt in foods, other properties, beyond taste and flavor, need to be considered as the lower salt product needs to match the original product for all product attributes. The main functions salt provides to food products are preservation, flavor, and processability (Kilcast & den Ridder, 2007). More specifically salt imparts its own salty taste and enhances other flavors (Breslin & Beauchamp, 1997), helps in food
preservation and water and fat binding (Mitchell, Brunton, & Wilkinson, 2009b), helps ensure microbial safety (Taormina, 2010), contributes to structure in meat and bread (Desmond, 2006; Man, 2007), contributes to texture and cooking performance of cheese (Guinee, 2004), and results in a fuller mouthfeel (Hutton, 2002). Dietary sodium can come from more than just salt, such as from sodium bicarbonate and sodium benzoate, which are used within food products as a leavening agent and a preservative, respectively (Busch, Yong, & Goh, 2013).

Interactions (intra-modal and cross-modal), as well as psychological factors, also influence taste perception. Keast and Breslin (2003) completed a thorough review of taste-taste interactions. As a general rule, they found that in binary taste mixtures at low concentrations there was taste enhancement, at medium concentrations there was a combination of suppression, enhancement, and linear effects, while at high concentrations, there was generally suppression (Keast & Breslin, 2003). For salt and sour tastes, at low and moderate concentrations, enhancement is observed, but suppression is observed at high sodium levels (Breslin, 1996). Salt has been found to suppress the bitterness of selected compounds as demonstrated by the split tongue methodology (Kroeze & Bartoshuk, 1985) whereby bitterness intensity was reduced when a mixture of the stimuli were applied together compared to when the stimuli were applied separately at the same time to different sides of the tongue. The degree of bitterness suppression by salt varied widely by bitterness compound (Keast, Breslin, & Beauchamp, 2001).

Salt has been found to enhance sweetness in mixtures (Keast et al., 2001). The enhancement of sweetness can be concentration dependent and research has shown that
salt enhances sweet at low concentrations but results in mutual suppression at higher intensities (Breslin, 1996). Taste interactions can become complex when adding salt into food matrices. One study found the addition of NaCl to three soups decreased bitterness and increased sweetness (Gillette, 1985).

In addition to interactions that occur intra-modally, interactions in taste-flavor perception, or cross-modal interactions, occur within food and beverages. Flavor can broadly be thought of as the activation of three independent sensory systems: taste, olfaction, and oronasal somatosensations (irritation, tactile, thermal) (Keast, Dalton, & Breslin, 2004). In general, odors contributing to olfaction can both enhance and suppress tastes. Keast et al. (2004) summarized odor-taste interactions. As stated in this summary, suprathreshold odors can enhance tastes, likely due to congruency of the pairing (Schifferstein & Verlegh, 1996), ‘learned synesthesia’ – one modality evokes qualities of another after frequent co-occurrence (Prescott, 1999; Stevenson, Boakes, & Prescott, 1998), or ‘dumping’ effects (Clark & Lawless, 1994) as cited in (Keast et al., 2004). Congruency of the pairing is important to the enhancement, as for example, strawberry aroma enhances sweet taste (Djordjevic, Zatorre, & Jones-Gotman, 2004b; Frank & Byram, 1988), but peanut butter odor does not increase sweetness and strawberry odor does not enhance the saltiness of sodium chloride (Frank & Byram, 1988). Thus, the enhancement impact of an odor on taste is both odorant and tastant dependent. The reverse can also occur whereby a taste can enhance an odor, for example the intensity ratings of ethyl butyrate (fruit odor) increase as the concentration of sucrose increases (Hornung & Enns, 1994).
Odors can also suppress taste. Carmel odor not only enhanced sweetness, but also suppressed sourness in a citric acid solution (Stevenson, Prescott, & Boakes, 1999). This pattern confirms the results seen in binary taste mixtures in which sucrose could suppress sourness. Odors not associated with salt could cause a reduction in saltiness perception, as carrot odor induced a decrease in the saltiness ratings in a low-salt (0.02M) solution (Lawrence et al., 2009).

‘Dumping’ effects (Clark & Lawless, 1994) can cause taste enhancement by ‘dumping’ an attribute’s intensity into a scale if there is not an appropriate scale for the perceived attribute. For example, there was significantly less sweetness enhancement when subjects rated, in addition to sweetness, the strawberry-flavor strength (Frank, Van der Klauuw, & Schifferstein, 1993).

The perceptual approach taken, essentially whether the odor and taste are perceived as a single entity (synthetic strategy) or multiple elements (analytical strategy), is an important determinant of how flavors are perceived (Prescott, Taylor, & Roberts, 2004). This has been demonstrated by how trained versus untrained panelists evaluate sweetness with maltol, whereby the trained panelists found no enhancement of sweetness when maltol was added to a sucrose solution, but the untrained panelists did find the maltol plus sucrose solution to be sweeter than the sucrose alone (Bingham, Birch, de Graaf, Behan, & Perring, 1990). Therefore, when designing sensory evaluation methods, both the type of panel and thorough questioning of the whole product profile are important to help prevent ‘dumping’ effects.

The mechanism by which odors can enhance tastes has been termed odor-induced changes in taste perception (OICTP) and has been found to be a centrally
mediated phenomenon (Djordjevic et al., 2004b). This was determined as separate delivery of olfactory and gustatory stimuli resulted in taste enhancement (Djordjevic et al., 2004b). Imagined odors influenced taste in similar way as perceived odors, just to a smaller extent (Djordjevic, Zatorre, & Jones-Gotman, 2004a).

Additionally, the presentation of the odor, whether presented orthonasally or retronasally, can impact the level of saltiness enhancement. The saltiness score was higher when the odor was presented orthonasally vs retronasally (Lawrence et al., 2009). These authors hypothesized that this effect could be due to the absence of salt on the tongue, as these solutions were presented with no salt. This could have led to decreased saltiness intensity evoked by odor, as the taste that was anticipated was not there, thus the odor-taste association was less likely to operate. Another potential could be a lower perceived odor intensity, as there could be a decrease of volatile concentration through the retronasal route compared to the orthonasal route due to mass transfer from the solution to the gas phase (Linfirth, Martin, Carey, Davidson, & Taylor, 2002). Neuroimaging studies have found potential sites of integration (De Araujo, Rolls, Kringelbach, McGlone, & Phillips, 2003), and the neurocognitive bases for multimodal food integration has been reviewed previously in depth (Verhagen & Engelen, 2006). It has been proposed that flavor perception depends upon neural process occurring in chemosensory regions of the brain (Small & Prescott, 2005) and that different activation patterns exist for unimodal vs bimodal presentation of same tastes and odors. As Lawrence et al. (2009) summarized, odor induced salt enhancement is centrally mediated based on associative memory, and just the internal representation of salt-associated odor is enough to induce the enhancement.
The observation that odors can enhance congruent tastes holds true for salty congruent odors enhancing salty taste. The first study to find odorant-specific enhancement of perceived saltiness induced by a salty-congruent odor did so with the addition of soy sauce to water (Djordjevic et al., 2004b). This effect, termed odor-induced saltiness enhancement (OISE), has been confirmed by others (Chokumnoyporn, Sriwattana, Phimolsiripol, Torrico, & Prinyawiwatkul, 2015; Djordjevic et al., 2004b; Stefanie Kremer, Mojet, & Shimojo, 2009; Lee, Lee, & Kim, 2015). OISE has also been found with other aromas. For example, the aroma of cheese, revealed by removing nose clips, enhanced the salty taste of cheese samples, most likely due to a congruency phenomenon (Pionnier et al., 2004). Similarly, sardine aroma was able to increase the salty intensity by 25% in a salt solution (Nasri et al., 2013). There was a significant OISE for the aromas of bacon, sardine, anchovy, peanuts, ham, chicken, Roquefort cheese, tuna, and Comté cheese in simple water solutions containing a small amount of salt (Lawrence et al., 2009); thus it can be concluded that well selected salt-associated aromas, i.e., retronasally perceived odors, can enhance the saltiness in solutions containing a low level of sodium chloride (Lawrence et al., 2009). Overall, the Lawrence et al. (2009) study demonstrated that odor quality and intensity are key driving factors of OISE potential.

OISE potential has been extended from aqueous solutions to solid food matrices. In model cheeses varying in texture, the addition of Comté cheese or sardine odors significantly enhanced the saltiness perception of cheeses containing the same salt concentration (Lawrence et al., 2011). The finding that OISE can occur within solid
foods contributes to the validity of the OISE strategy to compensate for sensory loss in low-salt food products (Lawrence et al., 2011).

The concentration of salt can impact the OISE potential. The salty enhancement effect of soy sauce addition in comparison with no odor or a strawberry odor was significant with the zero and weak salt concentrations, but not with the strong salt concentration (Djordjevic et al., 2004b). This concentration effect could possibly be related to the ceiling effect observed with strongest tastants and is consistent with previous studies (Dalton, Doolittle, Nagata, & Breslin, 2000; Djordjevic et al., 2004a; Schifferstein & Verlegh, 1996). Other studies confirm this concentration dependency of saltiness enhancement by odors and have also found that OISE depends on the salt concentration (Nasri, Beno, Septier, Salles, & Thomas-Danguin, 2011) whereby the OISE decreased when the intensity of saltiness increases.

In contrast, there are conflicting effects of odor intensity on taste enhancement. Taste enhancement by added odors may be dependent on the odor concentration (Cliff & Noble, 1990; Schifferstein & Verlegh, 1996; Stevenson et al., 1999). For sweetness enhancement with a lychee aroma, there was a concentration effect whereby the sweetness was enhanced at the low concentration, but with increasing aroma, the effect was less clear (Stevenson et al., 1999). Additionally, strawberry aroma enhanced sweetness only at low concentration (Schifferstein & Verlegh, 1996). For saltiness enhancement by varying odor intensity, conflicting results were reported. One study has demonstrated that OISE did not change with odor intensity, as there was no significant difference in saltiness perception when sardine aroma increased from 0.25 to 1 g/L for solutions (Nasri et al., 2013). Contrasting these studies, other researchers have found
that the higher the odor intensity, the higher the saltiness was perceived (Lawrence et al., 2009).

OISE potential can be different depending on the salt or other tastes present in the matrix. When tested with both KCl and NaCl, a higher OISE was found with KCl, potentially due to the initial saltiness of the aromaless solutions, as OISE decreases when intensity of saltiness increases (Nasri et al., 2013). When evaluated in mixtures containing salt, citric acid, and a sardine aroma, the highest OISE was observed in the acid-salty taste mixture (Nasri et al., 2013), and it has been suggested that sourness could include a salty dimension (Wise & Breslin, 2011). As OISE was highest in the more complex system, one may expect that cross-model odor(s)-taste(s) interactions could be even more efficient in complex food products. With the addition of savory aromas and KCl as a salt replacer, an approximate 30% sodium reduction was possible without a significant change in flavor profile of instant bouillons (Batenburg & van der Velden, 2011). These studies demonstrate that multisensory interaction between aroma(s) and taste(s) could be of use to lower salt levels for healthier food products.

To determine which additional aroma may be added to potentially enhance saltiness, one could have panelists rate expected saltiness for food products as research has shown a strong correlation between OISE level in solutions and the saltiness intensity that was rated for respective food names (Lawrence et al., 2009). While having a more limited effect on taste than perceived odors, imagined odors can enhance saltiness perception (Djordjevic et al., 2004b). Imagined soy sauce odor enhanced the perceived saltiness of a weak sodium chloride solution. However, odor imagery as a
sensory-specific form of mental imagery is still an open debate/paradox (Elmes, 1998; Royet, Delon-Martin, & Plailly, 2013).

Finally, the third component of flavor, oronasal somatosensations can also impact the saltiness of a food product. Literature on interactions with oronasal somatosensations and salt taste are still scarce. One example is the burn caused by pepper and perceived saltiness seem to interact (Prescott & Stevenson, 1995) as found in Laurila et al. (1996).

**POTENTIAL SALT REDUCTION STRATEGIES**

As discussed above, global salt consumption is above recommended levels, leading to unwanted health consequences, and thus global salt consumption needs to be reduced. But with all the unique functions and properties salt holds within foods, its reduction is complex. Due to this complexity, numerous strategies have been investigated to aid in achieving salt reduction targets.

Decreasing salt in food generally leads to a decrease in consumer acceptability (Breslin & Beauchamp, 1997). Thus, salt reduction must be approached strategically so as to not result in the loss of consumer acceptability of a product or prompt the addition of extra salt at the table. Jaenke et al. (2016) completed the first systematic review of ~50 studies that investigated salt reduction acceptance of reformulated food products to determine the extent to which salt could be reduced while maintaining consumer acceptability. This review reported that salt could be reduced by approximately 40% in breads (Adams, Maller, & Cardello, 1995; Bolhuis et al., 2011; Braschi, Gill, & Naismith, 2009; Ferrante et al., 2011; Girgis et al., 2003; Hellemann, Barylko-Pikielna, &
Matuszewska, 1990; Kremer, Shimojo, Holthuysen, Köster, & Mojet, 2013; La Croix et al., 2015; Miller & Jeong, 2014; Noort, Bult, & Stieger, 2012; Wyatt, 1983) and approximately 70% in processed meats (Almli & Hersleth, 2013; Campagnol, dos Santos, Terra, & Pollonio, 2012; Canto et al., 2014; Carvalho et al., 2013; Corral, Salvador, Belloch, & Flores, 2014; Corral, Salvador, & Flores, 2013; Galvão, Moura, Barretto, & Pollonio, 2014; Guàrdia, Guerrero, Gelabert, Gou, & Arnau, 2006, 2008; Lopez, Schilling, Armstrong, Smith, & Corzo, 2012; McGough, Sato, Rankin, & Sindelar, 2012; Monteiro et al., 2015; Pietrasik & Gaudette, 2014; Saha, Lee, Meullenet, & Owens, 2009; Sofos, 1983; Tobin, O'Sullivan, Hamill, & Kerry, 2012, 2013) without significantly impacting consumer acceptability. In addition, the influence of salt reduction on consumer acceptability varies according to product type (Jaenke et al., 2016). Thus, salt reduction can be completed successfully in a variety of processed food products, and potentially to large percentages.

To date, most of the studied strategies for salt reduction fall into one of three main principles: cognitive, chemical, or physical mechanisms. In more detail, these three main principles are to cause an increase in awareness or to shift saltiness preference with cognitive mechanisms, to use chemical stimulation that would cause saltiness perception to increase peripherally, or to physically enhance salt delivery to the taste buds by optimizing product structures. (Busch et al., 2013). When choosing a method, one should also consider what impact it could have on the label, i.e. will it result in an unclean label that consumers do not want to purchase, and one should consider potential price implications of the method.
Cognitive Salt Reduction Strategies

Numerous cognitive strategies have been proposed to describe the perception and acceptance of sodium-reduced meals. The main cognitive approach used in salt reduction is to create widespread willingness and a consumer need for sodium reduction (Busch et al., 2013). In Finland, increased awareness and education have been claimed as success factors for decreased salt intake (Pietinen, Valsta, Hirvonen, & Sinkko, 2008). Five other countries have reported the impact that this strategy had on sodium intake levels (Webster, Dunford, Hawkes, & Neal, 2011). These countries found creating a consumer willingness for salt reduction was more successful when led by the government and had multiple approaches, including raising consumer awareness, labelling activities, and product reformulation (Webster et al., 2011).

One of the most common methods for salt reduction is by gradual reduction, or the stealth approach. This method works by making incremental reductions to the amount of salt added to foods over an extended time period until the desired low salt level is achieved. This method has become the salt-reduction strategy of choice by many countries. The world action group ‘World Action on Salt and Health’ (WASH) encourages this approach, and it is currently being implemented by food manufacturers worldwide in countries such as Australia, UK, and Ireland (He & MacGregor, 2009). With this approach, consumers are able to adapt to new taste before further small reductions in salt occur (Dötsch et al., 2009).

In the gradual reduction method, one reduces the salt added to food by small amounts. Reductions of ~10 to 20% cannot be detected by human salt taste receptors and would not cause technical or safety issues with the food; this same process is
repeated in ~ 1-2 years (He & MacGregor, 2009). Consensus Action on Salt & Health, a UK group of specialists, claims that a 10-15% reduction in salt content cannot be detected by human salt-taste receptors (CASH, 2006). Salt reduction percentages greater than 10-15% may be possible in complex matrices such as frozen lasagna ready meals and frozen chicken curry ready meals in which 29% (1.05% to 0.75% NaCl) and 33% (0.6% to 0.4% NaCl) salt reductions, respectively, have been achieved with no difference in the perceived saltiness (Mitchell, Brunton, & Wilkinson, 2009a; Mitchell et al., 2009b).

Several sensory evaluations studies have been completed to investigate the potential of salt reduction by the gradual approach. It has been demonstrated that people can adapt to a diet with either higher or lower sodium, and their preferences change accordingly (Bertino, Beauchamp, & Engelman, 1982, 1986). Others have found that a 25% reduction could be obtained with 5% reductions weekly over the course of 6 weeks, while maintaining consumer acceptance (Girgis et al., 2003). Within the food industry, an example of this approach occurred between 1998-2005 when Kraft completed a 33% reduction in salt in their breakfast cereals and a 33% reduction in Kraft cheese spreads and snacks (Food Standards Agency, 2006).

However, the gradual approach presents several challenges in terms of consumer acceptability. One challenge is if only some food products on the shelves undergo a gradual salt reduction, the overall consumer palate may not adjust to this lower salt level. Another challenge is that eventually a level will be reached below which flavor and taste loss will be noticed by consumers, resulting in a significant risk of reduced sales (Kilcast & den Ridder, 2007). When implementing the gradual approach in the food
industry, one must be proceed with caution of labeling food products as low-salt, low-
sodium, or reduced salt as many consumers believe these products to be unpleasant and
perceive salt-restricted diets as bland and tasteless (Liem, Miremadi, Zandstra, & Keast,

Another cognitive method which may not be initially evident is the use of
crossmodal correspondences. Crossmodal correspondences are defined as the
compatibility effect between attributes or dimensions of a stimulus in different sensory
modalities (Spence, 2011). More specifically, the use of crossmodal impacts of basic
tastes and shapes to enhance saltiness perception may be a potential cognitive salt
reduction strategy. Previous studies showed that saltiness was associated with
angularity (Velasco, Woods, Petit, et al., 2016). This roundness/ angularity association
with tastes also applies to typefaces, whereby participants matched rounder types with
the word “sweet”, while matching more angular typefaces with the taste words “bitter,”
“salty,” and “sour” (Velasco, Woods, Hyndman, & Spence, 2015). The accumulation of
studies showing crossmodal relationships among shapes and basic tastes suggest shape
features of product design, particularly package design, could convey taste information
prior to product purchase. This could influence affective ratings of the product (Velasco,
Woods, Petit, et al., 2016), thus potentially enhancing saltiness in a reduced salt
product.

**Chemical Salt Reduction Strategies**

The strategies discussed in the section above mostly rely on cognitive
mechanisms to increase the saltiness perception. Chemical mechanisms that attempt to
use ingredients that taste salty or increase saltiness perception will now be discussed in brief. Salt substitution in which salt is replaced with other compounds is a common chemical salt reduction strategy. Several compounds that have been investigated for this application include potassium chloride, other potassium salts, calcium chloride, magnesium sulfate, magnesium chloride, ammonium chloride, organic acids, autolyzed yeast products, and hydrolyzed vegetable protein, as well as mixtures of these compounds (Reddy & Marth, 1991). The most commonly investigated of these compounds for salt replacement is potassium chloride (KCl) (Fregly, 1981; Li et al., 2008).

Potassium chloride has been widely used as a potential salt replacer to reduce sodium levels within foods (Toldrá & Barat, 2009) as it displays similar functional properties to salt (Guàrdia et al., 2008). Additionally, using potassium chloride as a salt replacer has the added benefit of the increased intake of potassium, which can exert a protective effect in individuals with sodium-induced hypertension (Haddy, 2006; Linas, 1991). Many studies report using potassium chloride as a salt replacer, and it is a common approach used within the food industry. A 50:50 ratio of salt to KCl is a common practical limit that is used within the food industry (Phelps et al., 2006) and this is product-specific. This replacement amount has been demonstrated in studies with cheese, fermented sausage, and vegetable juice which have found 50% of the sodium chloride could be replaced with potassium salts and not have a significant sensory effect (Adams, Maller, & Cardello, 1994; Guàrdia et al., 2006; Katsiari, Voutsinas, Alichanidis, & Roussis, 1997). When the same concentration of sodium (0.14%) was compared using NaCl or NaCl/KCl in vegetable juice, the perception of
saltiness was similar and the acceptability ratings did not differ from the higher concentration (0.25% to 0.6%) (Adams et al., 1994). Thus, a commercial salt substitute with equal concentrations of NaCl and KCl can replace higher concentrations of NaCl without affecting consumer acceptance in some food products (Adams et al., 1994).

Just as the gradual approach comes with limitations, so does using potassium chloride to replace salt. Challenges associated with potassium chloride include its associated bitter and metallic off-tastes, as well as its weaker salting capacity—the ability for the equivalent amount to result in the same amount of saltiness intensity perception (Armenteros, Aristoy, Barat, & Toldra, 2012; Frank & Mickelsen, 1969; Hooge & Chambers, 2010; Murphy et al., 1981). For example, when NaCl was replaced in a fish sauce with KCl, a replacement of more than 25% resulted in an unacceptable bitter taste (Sanceda, Suzuki, & Kurata, 2002). Still using some salt can help to mask some of the off-taste potassium chloride may contribute. For example, salt was found to adequately mask bitterness in samples containing up to 1.5% KCl (Olson & Terrell, 1981). Another example was found in NaCl-KCl water solutions, whereby all concentrations of NaCl suppressed bitterness of all concentrations of KCl, with both compounds ranging from 0.0 to 0.2M (Breslin & Beauchamp, 1995).

The mixture of KCl and NaCl has been found to elicit a higher perception of saltiness compared to sum of individual salty intensities of the components (Breslin & Beauchamp, 1995; Hooge & Chambers, 2010; Nasri et al., 2013). In addition, bitterness is masked when KCl is mixed with salt and results in a lower bitterness than KCl alone (Breslin & Beauchamp, 1995; Hooge & Chambers, 2010; Nasri et al., 2013). This enhancement effect of salt taste by KCl is thought to be due, in part, to the competitive
binding of Na+ and K+ in a system (Rosett, Wu, Schmidt, Ennis, & Klein, 1995). However, other studies show that NaCl and KCl do not have a synergistic effect on salty taste intensity (Lee et al., 2015).

Other compounds have been identified as able to help mask the bitterness contributed by potassium chloride. Indeed, trehalose and sucrose may mask bitterness at certain KCl concentrations, without masking saltiness (Ben Abu, Harries, Voet, & Niv, 2018). Commercial mixtures have also been developed with KCl, such as AlsoSalt® which is a mixture of KCl and the amino acid L-lysine monohydrochloride which acts as a ‘bitter blocker’ (Mitchell et al., 2009a).

Calcium chloride has also been commonly tested for its potential to replace salt. The saltiness of NaCl was found to be additive with the salty taste of calcium chloride (Lawless, Rapacki, Horne, Hayes, & Wang, 2004). As with potassium chloride, calcium chloride has limitations in its usage as a salt replacer due to the bitterness it contributes. To help overcome this bitterness, mixtures can be used. Mixtures with sucrose, citric acid, or sodium chloride have been found to suppress the off-tastes of CaCl₂, particularly bitterness (Lawless, Rapacki, et al., 2004).

Another potential substitution strategy to reduce sodium is the use of some sea salts to obtain the same salty taste as a food containing traditional salt, but have a lower sodium content (Drake & Drake, 2011). However, several sea salts used in the study actually had a higher sodium content than table salt on an equivalent weight basis (Drake & Drake, 2011). This study reported a correlation between sodium content and salty taste (r=0.62, P<0.05), but suggested that the other minerals do play a role in salty taste. Sea salts at equal sodium content were different in salty taste intensity, and time-
intensity parameters varied among salts at equivalent sodium concentration (Drake & Drake, 2011). The influence of trace minerals was minimal, but some flavors such as mineral, and metallic, and stronger intensities of umami taste and astringent mouthfeel were sometimes found in sea salts compared to table salt (Drake & Drake, 2011). Specifically, zinc salts were higher in astringency and umami sensation (Keast, 2003; Yang & Lawless, 2005), magnesium and calcium salts were higher in bitterness (Lawless et al., 2003; Yang & Lawless, 2005), and iron contributed a metallic flavor (Lawless, Schlake, et al., 2004; Yang & Lawless, 2005).

Another salt reduction strategy is the use of salt enhancers. While the line between enhancers and replacers is blurred, enhancers are defined as compounds that increase saltiness perception, but do not contain a significant amount of saltiness itself. (Kilcast & den Ridder, 2007). The use of enhancers is largely based on the presence of amino acids and nucleotides and include glycine salts, guanylic acid salts, inosinic acid salts, certain organic acids, herbs and spices (Mitchell et al., 2009b). These are typically high in glutamate and/or ribotides and rely largely on taste-aroma interactions such as the OISE effect discussed previously.

One potential way to induce OISE is with the use of herbs (Durack et al., 2008; Reddy & Marth, 1991). Indeed, adding herbs to a fresh soup reduced the amount of sodium added ad libitum; however consumers’ liking decreased in soup containing the highest level of herbs (Wang, Lee, & Lee, 2014). The addition of herbs have displayed limitations to their saltiness enhancement post-processing as adding herbs to canned soups did not change overall liking or the amount of salt added (Wang et al., 2014).
MSG, containing high levels of glutamic acid and mainly derived from the fermentation of molasses, is a commonly used taste enhancer that works by eliciting the umami taste receptor, which improves the balance and taste perception in food (Brandsma, 2006). In general, glutamates work through taste-taste interactions as discussed above whereby they increase umami and result in umami-salt interactions (Keast & Breslin, 2003; Mojet, Heidema, & Christ-Hazelhof, 2004). MSG has been used successfully in the reduction of sodium content in spicy soups (Jinap et al., 2016). However, MSG has limits as it also delivers extra sodium (Yamaguchi & Takahashi, 1984). There are some alternatives to MSG, including dicalcium glutamate which increases umami and salty notes (Ball, Woodward, Beard, Shoobridge, & Ferrier, 2002a; Carter, Monsivais, & Drewnowski, 2011).

Yeast extracts are commonly used to enhance existing food ingredients such as meat and spices by imparting bouillon-like, clean tastes in food as salt substitutes and/or flavor enhancers (Mitchell et al., 2009a). These extracts can contain higher glutamic acid content, higher nucleotide content, or a combination of both, depending on desired effect (Brandsma, 2006). In Europe, yeast extracts seem to offer the greatest benefit in search of low-sodium/low-salt products (Brandsma, 2006) by improving perceived flavors, acidity, mouthfeel, or saltiness, plus they allow for a “clean” label declaration as compared to other salt enhancers that may not. Studies by DSM Food Specialties (Delft, Netherlands) reported that yeast extracts can enable a 40-60% salt reduction without compromising palatability, mouthfeel, organoleptic structure, or authenticity (Brandsma, 2006). In this vein, several yeast-based flavor enhancers have been developed. Provesta® 512 is yeast-based flavor enhancer that is a low-sodium autolyzed
yeast extract containing a high level of naturally occurring 5’-nucleotides IMP and GMP (disodium inosinate and disodium guanylate), and it claims to amplify flavors and contribute to the umami effect (ABF Ingredients 2006—from Mitchell 2009). Three other yeast-based enhancers developed contain a KCl and autolyzed yeast, an autolyzed yeast, and a whole-cell yeast (Mitchell et al., 2009b).

In brief, other potential salt enhancers include disodium inosinate and disodium guanylate which are high in nucleotides so they can amplify the umami intensity of glutamate (Brandsma, 2006). Hydrolyzed vegetable protein is chemically broken down into component amino acids to help enhance flavor in food (Brandsma, 2006). Glycine and glycine monoethyl ester function to reduce the water activity and act as a salt enhancer for various types of sausages (Gelabert, Gou, Guerrero, & Arnau, 2003; Gou, Guerrero, Gelabert, & Arnau, 1996).

Both salt enhancement and salt replacement have challenges, especially when trying to maintain a clean label (Wilson, 2010), explaining why more strategies and combinations strategies are needed. One such example of combining strategies to reduce sodium was the replacement of sodium chloride with potassium chloride, along with added aroma. These combined strategies compensated for ~30% sodium reduction in instant bouillons without a significant change to the flavor profile (Batenburg & van der Velden, 2011).

Physical Salt Reduction Strategies

The strategies discussed in the section above mostly rely on the chemical stimulation to increase the saltiness perception peripherally. Designed product structures that
attempt to optimize the delivery of salt to the taste buds will now be discussed in brief. These methods include changing the spatial distribution of salt through surface coating (Dubois & Tsau, 1992; Fan, 1991; Shepherd, Wharf, & Farleigh, 1989), inhomogeneous salt distribution (Mosca, van de Velde, Bult, van Boekel, & Stieger, 2010; Noort, Bult, Stieger, & Hamer, 2010; Woods, Poliakoff, Lloyd, Dijksterhuis, & Thomas, 2010), and modifying salt content of each ingredient in multicomponent foods (Dijksterhuis, Le Berre, & Woods, 2010; Dijksterhuis, Boucon, & Le Berre, 2014; Guilloux, Prost, Courcoux, Le Bail, & Lethuaut, 2015). Other methods for the design of product structures for salt reduction involve the form of the salt added and include the encapsulation of salt (Noort et al., 2012), and changing the salt crystal size, shape, and morphology to change the rate of dissolution (US7923047 B2, 2011; Kilcast & den Ridder, 2007). The product structure may also be changed to allow for a reduction in salt content by altering the viscosity or thickness of a product, some examples include changing the viscosity of a solution (Baines & Morris, 1987; Christensen, 1980; Cook, Hollowood, Linforth, & Taylor, 2002; Koliandris et al., 2010; Moskowitz & Arabie, 1970; Yamamoto & Nakabayashi, 1999), using fewer gelling agents (De Loubens et al., 2011; Koliandris, Lee, Ferry, Hill, & Mitchell, 2008; Mills, Spyropoulos, Norton, & Bakalis, 2011; Moritaka & Naito, 2002; Wilson & Brown, 1997), thickener choice (Rosett et al., 1995), and use of fillers (Busch et al., 2013; Chiu, Hewson, Yang, Linforth, & Fisk, 2015; Goh, Leroux, Groeneschild, & Busch, 2010; Malone, Appelqvist, & Norton, 2003; Metcalf & Vickers, 2002).

Inhomogeneous salt distribution, the strategy whereby spatial distribution of salt is varied in semi-solid foods (Mosca, Bult, & Stieger, 2013), is thought to work as a salt
reduction strategy as the result of discontinuous stimulation of the taste receptors. It is believed to work by lowering the adaptation effect (Mosca et al., 2010), due to contrast effects (Noort et al., 2010), or due to consumers expectation of constant product (Woods et al., 2010). Inhomogeneous salt distribution has been tested in bread and a 28% reduction of salt was obtained (Noort et al., 2010).

In general, inhomogeneous salt distribution works best with solid products like sausage, cheese, and snacks (Stieger, Bult, Hamer, & Noort, 2009a, 2009b). However, there are still technical challenges for these product structures as one needs a large gradient, and salt migration during shelf life can affect this (Busch et al., 2013). For this strategy to be effective with liquid products, encapsulation or particulates in the liquid are needed. For encapsulation, double emulsions can be used (Garti, 1997), or encapsulation based on lipid molecules (Frasch-Melnik, Norton, & Spyropoulos, 2010). But the challenge remains of long term stability (Mellema, Benthum, Boer, Harras, & Visser, 2006). For liquid products with particulates, a soup with salted particulates was perceived as saltier than soup with same overall sodium content, but unsalted particulates (Busch, Knoop, Tournier, & Smit, 2008). Again, over a longer term, this approach would be limited due to salt diffusion and would only be suitable in products stored in a solid phase in which water is added to reconstitute, and that have a short consumption time after hydration so that the salt does not diffuse. Surface coating could be thought of as a specific subset of the inhomogeneous salt distribution strategy. If a product has a surface coating of salt, it will deliver increased saltiness intensity than if the same amount of salt was incorporated into the food (Fan, 1991; Shepherd et al., 1989). However, this technique can result in the reduced acceptance of the product, as
demonstrated in a paté that was liked less by 30 consumers when the surface coating strategy was used (Shepherd et al., 1989).

The temporal contrast of salt delivery can increase salt perception (Busch, Tournier, Knoop, Kooymman, & Smit, 2009). The rate of salt release in the mouth may be a potential salt reduction strategy. Trained panelists found peak saltiness at 20-30 s of chewing potato chips, when the samples would normally have already been swallowed. These results suggest that a proportion of sodium consumption occurs after the product has been swallowed and thus does not contribute to sensory perception (Tian & Fisk, 2012).

Within multi-component foods, modifying the salt content of each ingredient may aid in salt reduction by the salty first bite leading to increased salt perception of the remainder of the product (Dijksterhuis et al., 2014). For example, in pizza, to maximize salt impact and allow for a 30% salt reduction without altering sensory properties, the salt should be preferentially placed within mozzarella-style cheese and tomato sauce, and the salt can be reduced to 0% in the pizza dough (Guilloux et al., 2015). In a model sandwich, layered distribution of salt within three sections, the outer, middle, and outer, was perceived as more salty than homogeneous distribution of same salt content by 11 trained panelists (Dijksterhuis et al., 2010). Thus, within multi-component foods salt levels should be examined within each component for maximum salt reduction potential.

A decrease in particle size can be used to help in salt reduction. This strategy can work by decreasing salt particle size or even other particles within a product. For example, a decrease in the salted ham particle size in flans increased the perceived
saltiness (Emorine, Septier, Thomas-Danguin, & Salles, 2014). Salt crystals that dissolved faster due to lower particle sizes or a hollow shape can lead to the desired taste with lower salt added in both meat paste and popcorn (US7923047 B2, 2011). Dendritic salt has voids throughout the crystal, thus drastically increasing exposed surface area, and thus the dissolution rate. Salts with finest crystal sizes gave a more rapid release of saltiness than the larger crystal sizes (Kilcast & den Ridder, 2007), but one cannot extrapolate time intensity results from a trained panel to consumer liking.

The use of fillers, such as oil or air bubbles, serve as a potential strategy to reduce salt by filling up volume so that less water needs to be added to the product. Therefore less salt is required to obtain the same salt concentration in aqueous phase (Busch et al., 2013). Oil droplets can form a filler phase, and can increase saltiness perception (Metcalf & Vickers, 2002; Yamamoto & Nakabayashi, 1999). This function may be due to the concentration of salt in the water phase (Yamamoto & Nakabayashi, 1999). However, oil can cause a mouth coating effect, so saltiness perception can decrease with higher concentrations of oil in oil/water emulsions (Malone et al., 2003; Yamamoto & Nakabayashi, 1999). Additionally, adding extra oil may be an unfavorable solution due to the addition of calories.

Using air bubbles as fillers may cause air inclusions which can enhance sodium delivery and perception (Chiu et al., 2015). With air bubbles, the salt taste depends on the salt concentration in aqueous phase, regardless of volume of air bubbles (Goh et al., 2010). Air bubbles may be more efficient fillers compared to oil/fat or solid fillers as they do not appear to reduce the transfer of salt to the taste buds (Busch et al., 2013). The main disadvantages of fillers is that other sensory qualities may be changed and the
stability of fillers needs to be maintained over time to continue to work successfully (Busch et al., 2013).

**REDUCTION STRATEGIES IN READY TO EAT PRODUCTS**

Now that many of potential salt reduction strategies have been explored, the application of utilizing these strategies within ready to eat products will be discussed. As discussed above, intra-modal and cross-modal interactions can enhance or reduce saltiness intensity perception. Thus, it is not surprising that the complexity of food can modify intensity of a specific taste (Laurila, Lähteenmäki, Rita, & Tuorila, 1996), and that the food matrix has an influence. For example, saltiness was perceived differently in water and tomato juice (Pangborn & Pecore, 1982). Thus, responses to saltiness in one matrix cannot be extrapolated to a more complex matrix. Additionally, when investigating salt reduction in complex food matrices, it is important to consider that the just tolerable difference, the distance from the ideal that is just discriminated in preference ratings, can be larger than the just noticeable difference, suggesting preference may not be as sensitive to the changes in the individual attributes (Conner & Booth, 1992).

Many ready to eat food matrices have been studied for potential salt reduction. Some of these include tomato soup (Ghawi, Rowland, & Methven, 2014; Hooge & Chambers, 2010; Wang et al., 2014), pumpkin soup (Ball, Woodward, Beard, Shoobridge, & Ferrier, 2002b), vegetable soups (Mitchell, Brunton, & Wilkinson, 2013), beef soups (Lee et al., 2015), frozen lasagna meals (Mitchell et al., 2009a), frozen curry meals (Mitchell et al., 2009b), stir fried pork (Goh et al., 2011), meatloaf (Adams et al.,
Soups are a commonly consumed food product in the United States (Smiciklas-Wright, Mitchell, Mickle, Cook, & Goldman, 2002) that contribute a large proportion of consumed sodium to the diet (CDC, 2012). Accordingly, soups have been extensively investigated for their salt reduction potentials utilizing reduction by stealth, replacement with potassium chloride, and enhancement with monosodium glutamate, calcium diglutamate, and herbs (Allison & Fouladkhah, 2018). Both the use of herbs and spices, as well as using potassium chloride, have been investigated in tomato soup (Ghawi et al., 2014; Hooge & Chambers, 2010). The inclusion of herbs and spices enhanced the perception of the salty taste of a low salt soup (0.26% w/w) to the same level as the standard salt soup (0.5% w/w) (Ghawi et al., 2014).

The first study to investigate tomato soup as a medium for potassium chloride incorporation found that that a 48% sodium reduction was possible in tomato soup with the addition of 0, 0.45, 0.6, or 0.75% KCl without significant impact on the saltiness intensity or bitterness perception (Hooge & Chambers, 2010).

The addition of glutamate may allow for substantial reductions in the sodium content of soup, without significant deterioration of taste. As evidence in a pumpkin soup, a 50 or 85 mM NaCl soup with added calcium di-glutamate (CDG) or MSG was rated as high as, or higher than, a 150 mM NaCl soup free of added glutamate on 5 of 6 scales (liking, flavor intensity, familiarity, naturalness, richness). (Ball et al., 2002a). While CDG and MSG were found to have equivalent effects, CDG permitted a greater reduction in sodium intake as it did not contain sodium itself (Ball et al., 2002a).
Vegetable soups with salt reductions up to 48% (from control soup at 0.93% NaCl) can be achieved without affecting consumer liking with the use of either 0.15% added rosemary or with 0.1% added lactoferrin hydrolysate (Mitchell, Brunton, & Wilkinson, 2013).

Combinations of salt reduction strategies have been investigated in soups. In beef soup, a combination strategy of using KCl and salty-congruent odor (i.e. soy-sauce odor) found that when sodium was substituted with KCl above the consumer rejection threshold (CRT) concentration, consumer acceptability and sensory profile were mostly recovered (Lee et al., 2015). However, the saltiness perception was not fully recovered. Furthermore, when below the CRT the consumer acceptability was not recovered using KCl as substitute (Lee et al., 2015). The study found the potential to use salty-congruent odor as final touch to induce salty taste, but noted that it is important that these odors are harmonized to the food system and have no artificialness to be successful in this task (Lee et al., 2015).

When performing salt reductions in soups, one must also be aware of potential labeling impacts on consumer perception (cognitive reduction mechanisms). For example, in a chicken soup, the salt intensity was expected to be lower in soup labeled “now reduced in salt” compared to soup without such a label (Liem, Toraman Aydin, et al., 2012). These results showed that labels that notify reduction in salt may have adverse effect on consumers’ expectation and on actual perceived taste of products. Indeed, reduced salt labels generated a negative taste expectation and actual taste experience in terms of liking and perceived saltiness in soups (Liem, Miremadi, et al., 2012). The perceived saltiness of the sodium-reduced soups decreased more, and the
consumers added more salt when soups had a reduced-salt label (Liem, Miremadi, et al., 2012). Location of consumption can also have an impact on perception. Reduced salt chicken noodle soups were less liked in a central location, but there was no difference in liking when consumed at home (Willems, van Hout, Zijlstra, & Zandstra, 2014). The above studies demonstrate all the complexities and challenges encountered when reducing salt in soups, a complex matrix. However, more complex is the investigation of salt reduction in prepared meals.

Several studies have investigated salt reduction strategies in prepared meals using reduction by stealth, replacement by KCl and AlsoSalt®, and enhancement with Provesta®, odors, and flavor addition such as soy sauce, garlic, and pepper in prepared meals. The stealth approach has been found to have success to a certain level of salt reduction in both frozen lasagna ready meals and frozen chicken curry ready meals (Mitchell et al., 2009a, 2009b). In frozen lasagna, NaCl could be reduced from 1.05% to 0.75% without a significant difference being observed in differences tests. The salt could be reduced by another 0.2% (down to 0.55%) with the addition of KCl without compromising consumer acceptability, salty taste, or sensory preference for the meal (Mitchell et al., 2009a). Mitchell et. al (2009) also replaced salt with AlsoSalt® and Provesta® 512 in the lasagna meal, and found differences compared to the control salt sample.

In the frozen chicken curry ready meal, salt was reduced to 0.4% without detecting a difference in saltiness when compared to a typical control meal at a salt level of 0.6% (Mitchell et al., 2009b). Again as seen with the lasagna, with additional salt
substitutes (KCl and AlsoSalt at 0.4%), salt could be further reduced to 0.2% with no noticeable difference in saltiness perception (Mitchell et al., 2009b).

Various other ready-to-eat meals have been investigated for their salt reduction potentials by various salt reduction strategies. In stir fried pork a 43% salt reduction was achieved by enhancement with soy sauce, and this resulted in an increase in pleasantness (Goh et al., 2011). In meatloaf, reduction by stealth allowed for a 53% reduction (0.59% to 0.31% sodium) with no significant difference in saltiness or consumer acceptability (Adams et al., 1995). In a chili con carne meal, no significant difference in acceptability scores were noted when varying levels of salt ranging from 0-0.68% salt added (Ainsworth et al., 1993). This result suggests that reduction by stealth may be successful in this particular matrix. In ratatouille, the salt could be reduced from 0.85% to 0.17% without impacting overall acceptability (Ainsworth et al., 1993).

In mashed potatoes, added garlic or pepper to enhance saltiness perception have been investigated (Laurila et al., 1996). In unflavored and garlic-flavored mashed potato, concentrations less than 0.36% NaCl and greater than 0.82% NaCl, and for pepper-flavored, less than 0.31% NaCl and greater than 0.83% NaCl, were required to obtain statistically significant differences in acceptance responses compared to the reference concentration of 0.6% NaCl (Laurila et al., 1996). This study suggested that as foods become more complex, it may be less possible to differentiate between levels of one substance such as salt (Laurila et al., 1996). Also, it is important to remember that noticeable intensity difference in individual tastes and flavors may not translate to an altered preference for a food product. Specifically, within complex meals, a reduction in
salt may not affect consumer preference as salt taste may not be the main reason for liking a food product (Mitchell et al., 2009b).

In conclusion, with the negative health implications of high sodium intake strategies to reduce sodium within the food supply are expanding and continually being researched in different matrices for their potential applications. It has become evident that one strategy alone is not enough to reach desired reduction targets, rather combinations of strategies are required.
CHAPTER III
IDENTIFICATION OF A SALT BLEND: APPLICATION OF THE
ELECTRONIC TONGUE, CONSUMER EVALUATION,
AND MIXTURE DESIGN METHODOLOGY

ABSTRACT

Replacement of NaCl with other salts is becoming increasingly common as part of a salt reduction strategy, but these salts may confer unwanted sensory changes. Therefore, the objective of this study was to determine the relationship between consumer perception and electronic tongue detection of different salts and their mixtures currently used in salt reduction. NaCl and replacement salts (KCl and CaCl₂) were identified, and using mixture design methodology, mixtures (n=10) were prepared in aqueous solutions and validated in tomato soup. A potentiometric electronic tongue, panelists with orientation (n = 30), and a consumer panel (n = 94 - solutions; n = 100 - soups) were used to evaluate the samples. Significant differences were found between salt mixtures in solutions and soups by both panelists and consumers (p < 0.05). Electronic tongue analysis showed a high discrimination index (D.I. = 96%) indicating distinct differences among the salt mixtures, and strong positive correlations (R² > 0.90) were found between sensory and electronic tongue data. Upon application of contour plots and desirability function analysis, an optimal replacement value was identified as one containing 96.4% NaCl, 1.6% KCl, and 2.0% CaCl₂. Additional salt blends could be created to continue to reduce NaCl and increase the other two salts, for further potential health benefits, without significantly impacting predicted acceptance scores. Results
from this study indicate the potential for the electronic tongue, sensory evaluation, and mixture design methodology to work together during product reformulations to achieve salt reduction targets.

**PRACTICAL APPLICATION**

The results show that salt mixtures vary in perception and acceptance in different matrices, and thus should be evaluated on a product by product basis. With its ability to discriminate among various salts, the application of the electronic tongue could be useful for industry in the development of products with different salt formulations to reduce NaCl within processed foods. Additionally, mixture design can help find a predicted optimum mixture for the product under investigation.
INTRODUCTION

Replacement of sodium chloride (NaCl) with other salts, particularly potassium chloride (KCl), is becoming increasingly common as part of a salt reduction strategy (Allison & Fouladkhah, 2018). The replacement of NaCl with KCl and calcium chloride (CaCl₂) could not only reduce the negative impacts on health by the overconsumption of NaCl, but have additional benefits by adding potassium and calcium into the diet. Many studies support the linear relationship between sodium intake and blood pressure, as reviewed by He and MacGregor (2010). With raised blood pressure being the leading cause of death worldwide, further research has now shown that accurately measured sodium intake shows a linear relationship with mortality (He et al., 2018). In contrast, potassium rich diets are associated with a decrease in blood pressure (Aburto et al., 2013). Furthermore, as salt intake is increased, so is calcium excretion, possibly leading to a negative calcium balance which may mobilize calcium from bone (Devine, Criddle, Dick, Kerr, & Prince, 1995). As potassium and calcium intakes are both commonly below recommended levels within the American population, and sodium consumption levels are much above recommended levels (Karppanen, Karppanen, & Mervaala, 2005), replacement of the sodium with potassium and calcium could have substantial health benefits to the individual, as well as to society, by reducing the growing burden of non-communicable diseases, and thus should be pursued by the food industry (Neal et al., 2007).

However, the use of salt substitutes comes with many challenges; one challenge to their use is that these other salts may confer unwanted sensory changes. KCl has a pronounced bitter/chemical/metallic taste (Sinopoli & Lawless, 2012). CaCl₂ is
commonly described as predominately bitter with sour components (Lawless et al., 2003; Tordoff, 1996; Yang & Lawless, 2005). Mixture utilization could be of use in addressing the bitterness perceived in the salt substitutes, as NaCl has been found to suppress the bitterness of both KCl and CaCl₂ (Breslin & Beauchamp, 1995; Lawless, Rapacki, et al., 2004). Further, placing these salts into a more complex matrix, such as tomato soup chosen for this study, may help in masking bitterness, as citric acid and sucrose have been found to suppress bitterness and metallic tastes of CaCl₂ (Lawless, Rapacki, et al., 2004). This suppression may be useful when placing CaCl₂ into a tomato soup matrix, as citric acid is the dominant organic acid in tomatoes and sucrose can be an important sugar in tomatoes, depending on the variety (Agius, von Tucher, Poppenberger, & Rozhon, 2018). Sucrose also has been found to reduce the bitter-metallic tastes of KCl (Ben Abu et al., 2018).

Studies within literature that compare these three salts and their mixtures by mixture design methodology within aqueous solutions or within a food matrix are lacking. In fermented sausages, one study investigated substitution of NaCl with KCl and CaCl₂, finding that the resulting product was still considered acceptable in texture and color properties (Gimeno, Astiasarán, & Bello, 1999), and guaranteed the hygienic quality of the product (Gimeno, Astiasarán, & Bello, 2001). Additionally, studies investigating the application of the electronic tongue to salts are limited. The taste profile of low-sodium cheeses with different salt replacers has been measured by the electronic tongue (Taste-Sensing System SA-402B) and found cheese with 30% KCl and 70% NaCl had the closest taste profile to the control cheese (Carmi & Benjamin, 2017). Given the evidence of electronic tongues as rapid analytical tools (Ross, 2009), their use...
to complement human sensory evaluation in product development and reformulation to achieve population salt intake reduction targets of 30% by 2025, as established by the WHO, could be of immense benefit to industry (WHO, 2012).

Therefore, the objective of this study was to determine the relationship between consumer perception and electronic tongue detection of these three different salts and their mixtures that are currently used as a salt reduction strategy. Previous research on salt suppression and enhancement was considered in the selection of salt combinations for this study. The saltiness of NaCl is considered to be additive to the salty taste of CaCl₂, while the bitterness of CaCl₂ is suppressed by NaCl (Lawless, Rapacki, et al., 2004). Further, adding NaCl in combination with KCl increased the perceived saltiness and decreased the perception of off-tastes, such as bitter, chemical, and metallic (Sinopoli & Lawless, 2012). Additionally, this study investigates the application of the salts mixtures from a model aqueous system to a tomato soup to determine potential perception changes due to incorporation into a complex matrix.

**MATERIALS AND METHODS**

*Materials*

Food grade sodium chloride (NaCl) (Macron Fine Chemicals, Avantor Performance Materials, Center Valley, Pa., U.S.A.), potassium chloride (KCl) (JT Baker, Avantor Performance Materials), and calcium chloride (CaCl₂) (Macron Fine Chemicals) were the salts used in this study. Additional materials used for the orientation session included sugar (Walmart brand, Bentonville, Ar., U.S.A.), citric acid (≥99.5%, Sigma-Aldrich, St. Louis, Mo., U.S.A.), MSG (Accent, Parsippany, Nj., U.S.A.), quinine sulfate (Sigma-Aldrich), and alum (McCormick, Hunt Valley, Md., U.S.A.). No-salt added
tomato sauce (Hunt’s, Omaha, Ne., U.S.A.), chopped frozen onions (Safeway brand, Pleasanton, Ca., U.S.A.), cut frozen carrots (Safeway brand), celery (Safeway produce), and spices (McCormick)- oregano, basil, marjoram, thyme, and bay leaf were used for the preparation of tomato soups. For all sensory panels, unsalted tops saltine crackers, plastic cups used as cuspidors, and napkins were purchased from Safeway (Pullman, Wa., U.S.A.). For solutions, 2 oz SOLO plastic soufflé containers with lids were used (Dart, Mason, Mi., U.S.A.) and for soups, 6 oz insulated white foam bowls with lids were used (Dart). MilliQ water was obtained through purification (EMD Millipore, Billerica, Ma., U.S.A.). The reagents for the electronic tongue analysis (sodium chloride, hydrochloric acid, and monosodium glutamate) were obtained from AlphaMOS (AlphaMOS, Toulouse France) and each was prepared at 0.01M concentrations.

**Salt Concentrations**

NaCl and replacement salts (KCl and CaCl$_2$) were identified, and using mixture design methodology, mixtures (n=10) were prepared in aqueous solutions (water) and validated in tomato soup. The concentration of NaCl for the target solution and target soup, 93mM, used in this study was selected based on a 30% reduction from the average concentration of salt added in tomato soup to reach a level of saltiness that was considered “just about right” (JAR) (Wang et al., 2014). This concentration was also selected based on a 30% reduction of the average salt concentration in 28 commercially available soups.

In this study, the goal of the mixture design was to identify an optimum mixture of the three salts using response optimization to produce a soup that was similar to the target soup in acceptance of all the attributes as evaluated by a consumer panel. To
determine the concentration to use of each of the 3 salts in the mixtures, an experienced panel (n=10) tasted solutions of NaCl and KCl at 93mM (target concentration), 80mM, 70mM, and 60mM as well as CaCl$_2$ at 29.8mM, 25.6mM, 22.4mM, and 19.2mM and rated them for bitterness, saltiness, and overall intensities along a 9-point scale from not intense (=1) to extremely intense (=9). The concentrations of CaCl$_2$ in the solutions were reduced by 32% from the NaCl solution concentrations as this reduction in concentration produced a similar intensity between the two salts (Van Der Klaauw & Smith, 1995). Based on results from the intensity data from the experienced panel, 70mM NaCl, 70mM KCl, and 22.4mM CaCl$_2$ were selected to use in the mixture design as no significant overall intensity difference was found among them (analysis not shown). The layout of the mixture design is shown in Table 1.

**Soup Preparation**

Soup composition and preparation was modeled after a previous study (Wang et al., 2014). The day prior to making soup, several preparation steps were performed. The frozen carrots and onions were weighed into labeled freezer Ziploc® bags and frozen. The celery was chopped to ~1.3 cm long and wide and ~0.5 cm thick, weighed into a labeled Ziploc bag, and refrigerated. All herbs and salts were weighed into labeled 4 oz soufflé cups, covered with a lid, and stored at room temperature (~22 °C). Tomato sauce was weighed into in labeled glass beakers, covered, and refrigerated. Water was weighed into labeled Nalgene bottles and stored at room temperature (~22 °C). The soup formulations are described in Table 2.

On the morning of the sensory evaluation panel, soups were prepared as follows. All vegetables (carrot, celery, and onion) and herbs (oregano, basil, marjoram, thyme,
and bay leaf) were added to a stock pot and cooked over medium heat (~105°C) for 5 min. The tomato sauce was added, brought to a boil, and cooked for 3 min. The water and salt were added and brought to a simmer. The soup simmered for 10 min, while maintained at 95°C ± 5°C and being stirred continually. Large pieces of herbs were removed. The soup was blended until a smooth and consistent texture was achieved with no visible chopped vegetables present. The prepared soup was poured into glass jars, lids were placed on each jar, and jars were placed into a water bath to maintain a temperature of 70°C ± 3°C. Twenty-five minutes before each evaluation session, 25 mL of each soup was placed into a white foam bowl labeled with a 3-digit code, covered with a lid, and placed under a food warmer (Hatco Corporation, Milwaukee, Wi., U.S.A.) at setting 6 to maintain temperature.

Electronic Tongue Analysis

A potentiometric electronic tongue (Astree II electronic tongue unit, Alpha MOS, Toulouse, France) equipped with an auto sampler (LS48) analyzed the solutions and soup samples based on their response to sensors for non-volatile compounds (saltiness, sourness, sweetness, umami, metallic, bitterness and spiciness). The analysis was conducted as previously described (Diako, McMahon, Mattinson, Evans, & Ross, 2016).

Briefly, the salt solutions were equilibrated to room temperature and the tomato soups were filtered through P8 Fisher filter paper (Fisher Scientific, Suwanee, Ga., U.S.A.). Prior to sample analysis, the electronic tongue was prepared by performing conditioning, calibration, and diagnostics. This was followed by an overnight hydration of the set #5 sensors in 25 ml reagent grade Milli-Q filtered water. A confirmatory diagnostic run was performed before sample analysis, and run procedures were
performed as previously described (Diako et al., 2016). A reference solution of 93mM NaCl was used for all analyses of solutions, while the soup with the target concentration of 93mM NaCl (0.54% NaCl) was used for the reference for all analyses of soups.

Sensory Evaluation – Panelists with an Orientation Session

Panelists (n = 30) were recruited from the Washington State University community through email to the listserv from Compusense Cloud (Guelph, Canada) scheduling software. All panelists signed a consent form that was approved by the WSU Institutional Review Board for the use of human subjects prior to any participation. The panel consisted of 18 females and 12 males between the ages of 22 and 60 with an average age of 33.

A 30 min orientation session was conducted to familiarize panelists with the sensory terms for which they would be evaluating. The orientation training was used to ensure that panelists understood the attributes of interest. The panelists were asked to not eat, drink, or smoke for at least 1 hour prior to a session. The difference between a qualitative and quantitative aspect was explained to the panel as well as how this applied to using the labeled magnitude scale (LMS). The attributes of interest were first described to the panelists as previously described (Lawless et al., 2003). Panelists were then given the following references to further strengthen their understanding of the attributes: 0.15 M sucrose for sweetness, 0.32 M NaCl for saltiness, 0.019 M citric acid for sourness, 0.09 mM quinine sulfate for bitterness, 0.009 M monosodium glutamate for umami, 1 g/L alum for astringency, and a sanitized copper penny was used as a metallic reference (Lawless et al., 2003). Between each reference, panelists rinsed with DI water.
After completing the orientation session, panelists completed four evaluation sessions. In sessions one and two, panelists evaluated the ten solutions (five on each day), plus the target solution, 93 mM NaCl. In sessions three and four, panelists evaluated the ten soups (five on each day), plus the target soup, 93mM NaCl. All intensities were evaluated on a labeled magnitude scale. This scale was bound by “no sensation” at the bottom and “strongest imaginable” at the top with roughly logarithmic spacing (Green, Shaffer, & Gilmore, 1993). Although not displayed to the panelists, these anchors were at 0 and 2 along the scale, with roughly logarithmic spacing along the scale.

Evaluation of the solutions and soups took place in individual tasting booths under white light at the Washington State University (WSU) Sensory Evaluation facility, a member of the Compusense at-hand Academic Consortium on the WSU campus in Pullman, WA. Samples were presented in a randomized complete block design. Solutions were served in soufflé cups (~15 mL) at room temperature, ~22°C, covered with a lid, and labeled with 3-digit random codes. Soups were served in white foam bowls (~25mL) with lids at ~70°C and labeled with 3-digit random codes. Between samples, breaks were required in which panelists used the provided unsalted crackers and Milli-Q water for palate cleansing. A one-min break between samples was forced to minimize fatigue due to tasting. All panelists were given a small gift card incentive for their participation.

**Sensory Evaluation- Consumers**

Consumers (solutions: n = 94; soups: n = 100) were recruited from the Washington State University community through email to the listserv from Compusense.
scheduling software. Prior to participation, all consumers signed a consent form that was approved by the WSU Institutional Review Board for the use of human subjects. The solutions panel consisted of 64 females and 30 males between the ages of 20 and 71, with an average age of 36. The soups panel consisted of 62 females and 38 males between the ages of 20 and 77, with an average age of 36. To reduce bias, consumers that previously participated in the panel with orientation did not participate in the consumer panel. Sample presentation was the same as described above, but instead of being required to attend all 4 sessions, consumers were required to attend both sessions of the same matrix, i.e. both sessions of solutions or both sessions of soups. Consumers evaluated the solutions and/or soups on a 9-point hedonic scale for their liking of salt, sweet, sour, bitter, umami, and overall liking.

**Mixture Design Analysis**

To investigate an optimum blend of salts that was closest across acceptance of all attributes to the target soup, mixture design analysis was utilized. First, mixture regression analysis was completed for each attribute evaluated by the consumer panel by starting with the most complex model and simplifying the model if significance was not found. This was completed by starting with the special cubic equation as a model for an attribute, and if this model was not significant for an attribute, then the quadratic equation was investigated, followed by the linear model. These polynomial regression models have been described previously (Scheffé, 1958). The linear model represents the effect of the singular salts, the quadratic model adds the synergistic effect of the binary mixtures, and the special cubic model adds to the synergistic effect of tertiary blends.
After determining the best fit model for each attribute, contour plots were created to determine optimal blend regions. These contour plots for each attribute were then compiled into one overlaid contour plot to find a desirable or feasible region. Subsequently, response optimization was completed by maximizing the consumer acceptance of attributes ($d$) to find an overall desirability ($D$) of the salt blends that was closest to the target soup, a soup containing a 30% reduction of NaCl compared to the concentration found in a soup that was just-about-right based on saltiness perception (Waldrop & Ross, 2014). The desirability function was developed by Derringer and Suich (1980) and has recently been described by Waldrop and Ross (2014). The lower and upper bounds were set to $-1/2 \text{SD}$ and $+1/2 \text{SD}$ of the target soup, respectively, and the target was the average score of the target soup with the goal selected as hitting the target value. All weights were assigned to 1 as it was not more or less important for each attribute’s acceptance average score to reach the target value. The geometric mean of all $d$’s \( \left( (d_1 \times d_2 \cdots \times d_k)^{1/k} \right) \) was calculated to determine $D$. $D$ has a range of 0 to 1, with 1 representing the ideal case and 0 indicating that one or more responses are outside their acceptable limits.

Statistical Analysis

Data analysis was accomplished using a two-way ANOVA for the panelists and treatment effects for the consumer panel, and a two-way ANOVA for the panelists and treatment effects with interactions for the panelists with orientation using XLSTAT (Addinsoft, Paris, France). Mean comparison for the treatments was completed with Tukey’s HSD using XLSTAT. Solutions and soups evaluated by the panel with orientation were further analyzed by principal component analysis and a partial least
squares correlation biplot to relate the panel with orientation to the consumer panel using XLSTAT. Principal component analysis, computation of discrimination index, and partial least square regression of electronic tongue data to panelists with orientation were conducted using the Astree® AlphaSoft software (version 12.44; Alpha MOS) (Diako et al., 2016). The loadings and scores from the PCA obtained from the AlphaSoft software were plotted as PCA biplot using R Base Graphics (R Core Team, 2017). Optimization analyses described above were performed with Minitab 16 (Minitab Inc., State College, Pa., U.S.A.). Significance was defined as p<0.05.

RESULTS AND DISCUSSION

Sensory Evaluation – Panelists with an Orientation Session

Table 3 summarizes the ANOVA results from the panelists with an orientation session. As may be expected with only a short orientation to the attributes, the panelist effect was significant for all attributes (Chambers, Allison, Marie, & Chambers, 2004). Despite this panelist effect, panelists distinguished among treatments, with significant differences found in all evaluated attributes, except sour, for solutions, and all attributes, except sour and ‘other’, for soups (p<0.05).

Specific differences among these treatments are shown in Table 4. All solutions were perceived to be less salty than the target solution. The same salt mixtures were evaluated within soups to compare to the target soup, a 93mM NaCl soup – a 30% salt reduction from a soup that was considered ‘just-about-right’ based on saltiness perception. Several treatments were not significantly different from the target soup in their saltiness perception, including the treatments NaCl, Center, NaCa, NaK, KDom,
and NaDom. The range of perceived saltiness intensity as evaluated along a 0-2 LMS
scale narrowed from 0.3-1.5 in solutions to 0.9-1.3 when evaluated within soup.

Results highlight the importance of performing sensory evaluations in the matrix
of interest as model solutions can give very different results from the end product.
Similar conclusions have been demonstrated in water solutions versus a more complex
tomato juice, whereby patterns of response to saltiness for one could not be extrapolated
to the other (Pangborn & Pecore, 1982). The difference threshold was higher in the
tomato juice than in distilled water suggesting the added complexity of the system
influences detection (Pangborn & Pecore, 1982). Results in other food matrices show
similar findings (Laurila et al., 1996; Mitchell et al., 2009b); studies in mashed potatoes
demonstrated that as the food product becomes more complex, it may be less possible to
differentiate between levels of substances such as sodium chloride (Laurila et al., 1996).
In mashed potatoes, the just noticeable difference was 0.07% for unflavored and garlic-
flavored samples and 0.08% for pepper flavored samples, while in a separate study a
difference threshold of 0.2% was determined in a chicken curry ready meal (Laurila et
al., 1996; Mitchell, Brunton, & Wilkinson, 2009). The higher complexity due to the
contribution of more flavors from herbs and spices may increase the difference
threshold (Mitchell et al., 2009). In the present study, tomato soups formulated with
herbs may be masking differences of the saltiness perception in the different mixtures,
thus narrowing the saltiness intensity range perceived by the panelists compared to the
solutions.

Similar to the narrowing of range of saltiness perception when salt mixtures were
placed into soups, attributes that may be viewed as negatively influencing the
acceptance of the product also narrowed in range when placed into the soup matrix. Specifically, the intensity of bitterness decreased in range from 1 to 0.4 on a 0-2 LMS scale, metallic from 0.5 to 0.3, and drying from 0.4 to 0.2 when evaluated in solutions versus soups. Perceived sweetness intensity saw small differences in solutions (p<0.05), but when put into soups, differences in the mixtures were not observed (p>0.05). Umami intensity was the reverse of sweetness, whereas in solutions no differences were perceived, in soups, differences between the mixtures were observed. The perception of sourness was not different among salt mixtures in either the solution or soup matrix. In summary, the soup matrix complexity suppressed differences in the intensity of salt, sweet, bitter, metallic, and drying attributes compared to the solutions of salt mixtures, while bringing out differences in the salt mixtures in umami intensity.

To further investigate relationships among samples and attributes as evaluated by the panelists with orientation, PCA analysis of solutions and soups was performed. For solutions, the first two principal components described 72.25% of the variation observed within the data (Figure 1). PC1 was described by the contrasting relationships of bitter and drying with sweet and salty while PC2 was associated with umami and sour. Solutions that were dominant in sodium had higher intensities of sweet and salt, solutions with high amount of potassium in the mixtures were higher in metallic intensity, and solutions high in calcium were high in bitter and drying attributes. As sodium was added into the mixture, the profile change was reflected in the PCA results with samples moving more towards the center of the graph. The equal mixture of all salts, the center sample, was close to the center of the graph indicating that upon mixing, the salts are all equally contributing to the flavor profile.
In soups, similar results were observed as with solutions (Figure 2). The first two principal components described 76.56% of the variation observed within the data. PC1 showed contrasting relationships of bitter and metallic with sweet, salt, and umami. PC2 was defined by other and drying, in contrast to sour. As observed with the solutions, soups with mixtures high in sodium displayed higher intensities of sweet and salt. Within soups, umami was increasingly associated with the sodium dominant mixtures in comparison to the solutions. Soup mixtures high in potassium salt were higher in drying and metallic attributes, and soup mixtures high in calcium salts were higher in bitter and sour attributes. This is consistent with previous observations that show potassium and calcium salts to have bitter and metallic off notes associated with their use (Ben Abu et al., 2018; Cepanec, Vugrinec, Cvetković, & Ranilović, 2017; Lawless et al., 2003; Lawless, Rapacki, et al., 2004; Sinopoli & Lawless, 2012; Van Der Klaauw & Smith, 1995; Yang & Lawless, 2005).

Sensory Evaluation - Consumers

Mean separation for attributes evaluated by consumers in both the solutions panel (n = 94) and soups panel (n = 100) are displayed in Table 5. The target solution and soup were ranked the highest in acceptance of all attributes for both the solution and soup panels; however, acceptance rankings were not significantly different from some of the other salt mixtures within each panel. Solutions not significantly different in saltiness acceptance from the target were NaCl and NaDom. Soups not significantly different in saltiness acceptance from the target soup were NaCl, NaCa, and NaDom. Solutions and soups not significantly different in bitterness acceptance from the target
were NaCl, NaK, and NaDom. For overall acceptance, the target solution and soup were not significantly different from the NaCl or NaDom mixtures.

Similar acceptance with reduced amounts of sodium is consistent with previous research that demonstrated a variety of processed ready-to-eat meals can have the salt content reduced by 30% without affecting consumer acceptability of these products (Purdy, 2002). A 40% reduction was achieved without panelists detecting a difference in the taste in chili con carne (Mitchell, Brunton, & Wilkinson, 2011). In vegetable soup, salt was reduced by 30% and the acceptance did not change for either an elderly population or for children (Gonçalves et al., 2014). Studies in other food matrices show similar results (Girgis et al., 2003; Jaenke et al., 2016; Wyatt, 1983). A 25% salt reduction in bread and cottage cheese can be delivered while maintaining consumer acceptance (Girgis et al., 2003; Wyatt, 1983). Results from a systematic review suggests salt can be reduced by about 40% in bread and 70% in processed meats without significantly impacting consumer acceptability (Jaenke et al., 2016).

**Electronic Tongue Analysis**

The electronic tongue had a high discrimination index of 96 (Figure 3), indicating its ability to distinguish among the various salt solutions. As seen in the sensory results from the panel with orientation, solutions high in calcium were high in metallic and bitter responses as evaluated by the electronic tongue. Different to the results from the panel with orientation, the electronic tongue PCA showed solutions high in calcium also were high in umami and sweet sensor responses, potassium dominant solutions were weak in all seven attributes the tongue evaluated, and sodium dominant solutions were high in sour responses from the electronic tongue.
The results from the electronic tongue are congruent with current literature findings. CaCl$_2$ has been found to have a sweet taste at low concentrations of 10-20mM, similar to the concentration used in this study (22.4mM). The perception of sweet taste of CaCl$_2$ decreased as concentration increased, possibly due to bitterness becoming more prominent, causing potential intramolecular ‘mixture suppression’ (Lawless et al., 2003). Umami taste intensity was the highest in the CaCl$_2$ salt of the three salts, MgSO$_4$, MgCl$_2$, and CaCl$_2$, evaluated (Lawless et al., 2003). At a low concentration of 4mM, NaCl has been found to be more sour and bitter than salty dominant in taste (Murphy et al., 1981). These more subtle taste characteristics may have been less pronounced to the panelists with orientation in their classification of the salts, and thus not closely correlated in the PCA, but the electronic tongue was able to pick up these differences in the salt mixtures.

The tomato soups were also evaluated by the electronic tongue (Figure 4). The electronic tongue again had a high discrimination index of 95. Results of the PCA were similar to the sensory results from the panel with orientation, with soups dominant in sodium being higher in salty intensity and soups high in calcium being higher in bitter and metallic intensity. In contrast to the panel with orientation, the electronic tongue found that soups high in sodium were also higher in spicy and sour intensities, soups high in potassium were weak in the seven attributes evaluated by the tongue, and soups high in calcium were moderately high in umami and sweet intensities. Again, as in the solutions, the electronic tongue was able to pick up differences in the salt mixtures within the tomato soups that may have been suppressed by the presence of other tastes.

*Relationships Between Different Evaluations*
Table 6 displays correlation results between the panel with orientation and the electronic tongue. For solutions, correlation coefficients were high (>0.8) for salt, bitter, and drying, and for soups, correlation coefficients were also high (>0.8) for salt, sweet, bitter, and metallic. These high correlations are in agreement with previous studies that reported high correlations between trained panel evaluations and the response of a potentiometric electronic tongue (Diako et al., 2016; Waldrop & Ross, 2014). The attributes with lower correlation values may be due to the short training time, only 30 minutes of orientation, of this panel in comparison to an extensively trained panel, or that these attributes were not perceived differently among the different treatments. While a more trained panel may result in higher correlations, it is noteworthy that for the simple attributes evaluated in this study, a 30-minute orientation was sufficient to bring about many strong correlations to the electronic tongue.

For soups, the consumer liking data and panelist intensity ratings were analyzed using partial least squares correlation (Figure 5). Higher perceived intensities of salt, sweet, and umami by the panel with orientation were related to higher liking of attributes evaluated by consumer panel. The target 93mM soup, a 30% reduction from the JAR soup, was similar to the soups containing sodium, specifically the 100% 70mM NaCl soup formulation. Several soup formulations containing sodium clustered near this target soup which were close to higher liking scores, as well as higher intensities of umami, salt and sweet. Soups high in calcium were clustered by bitter and metallic while tomato soups with high amounts of potassium in the mixtures were higher in drying intensity. With the changing of salt mixtures within soups, a change in profile and acceptance of the soup was observed. For example, in the soups with sodium, when
adding in other salts, the soup was moved away from the 93mM target, as well as the 70mM NaCl formulation, and closer to the respective salt that had been added into the salt mixture. This demonstrates that as one mixes these salts together, a mixing of their perceived attributes occurs within the new treatment mix, and this impacts their acceptance. Thus, their mixture is a close to equal combination of the two independent salts qualities.

To summarize, the electronic tongue was highly correlated to the panel with orientation on several evaluated attributes in both solutions and soups. Additionally, higher perceived intensities of salt, sweet, and umami by the panel with orientation were related to higher liking of attributes evaluated by consumer panel. Therefore, a potential for future product screening would be to find solutions and soups associated with the salt, sweet, and umami sensors on the electronic tongue, and then run a consumer panel on these formulations to limit the number of samples that need to undergo consumer evaluation.

**Mixture Design Analysis**

The best fit models for each attribute, determined as discussed above, R² adjusted values, and equations are presented in Table 7. The special cubic model was significant only for umami, the quadratic model was significant for bitter, and for the rest of the attributes, salt, sweet, sour, and overall liking, only the linear model was significant. The different fitted models suggest that the effect of the different salts and their mixtures vary for each evaluated attribute. For umami, the interaction of all three salts was significant in the model and as it is a positive coefficient, this indicates that these components were acting synergistically. The interactions of NaCl and CaCl₂ and of NaCl
and KCl had significant positive coefficients in the model for bitter, and thus were acting synergistically. The salts acting synergistically in improving bitterness acceptance is consistent with previous research that demonstrates adding NaCl in mixtures with KCl decreases unpleasant side tastes associated with KCl, such as bitter (Sinopoli & Lawless, 2012), and adding NaCl to CaCl₂ suppresses perceived bitterness (Lawless, Rapacki, et al., 2004). The singular effect of the salts was significant in each model with NaCl having the largest effect on all evaluated attributes. These results demonstrate that for different attributes evaluated, the effect of the different salts and their mixtures vary in their synergistic potential in improving consumer acceptance.

Contour plots for each of the attributes that were evaluated by the consumer panel were created based on the respective models. These contour plots are displayed in Figure 6. Tomato soups with salt blends high in NaCl were found to be optimal in all evaluated attributes. All attributes were then combined into one plot to find one region of desirable mixtures in an overlaid contour plot (Figure 7). In this plot, the white space is the desirable or feasible region for a mixture that would be within ±1/2 SD from the target soup. Response optimization based on input parameters and determined models produced a blend of 96.4% NaCl, 2.0% CaCl₂, and 1.6% KCl as an optimal blend of salts in tomato soups (Figure 8). This blend gave an overall desirability (D) of 0.94 with individual desirability values (d) ranging from 0.82 to 1. With a range of 0 to 1 for desirability, these high numbers indicate this salt blend would result in high acceptance across the attributes evaluated by the consumer panel. Further evidence for this comes from the high predicted liking scores (5.7–6.5 – Figure 8), being at the levels seen in the target soup (Table 5).
CONCLUSION

A panel with a short orientation session distinguished among solutions and soups containing different salt mixtures. The results from both the panel with orientation and the consumer panel make it evident that testing in the desired matrix is of great importance as both intensity and acceptance scores were different between the aqueous solution and the tomato soup of the same salt mixture. Electronic tongue analysis discriminated among salt solutions and soups with high accuracy (D.I. = 96%), and it correlated highly with panelists for many attributes ($R^2 > 0.9$). Thus, the electronic tongue can be of great value to be used instead of or with sensory evaluation when evaluating salts. Specifically, the electronic tongue could be used for screening purposes to reduce the number of samples for consumer testing by finding solutions and soups associated with the salt, sweet, and umami sensors on the electronic tongue, and then performing consumer testing on this reduced number of formulations. Finally, mixture design analysis produced a predicted optimal salt blend in tomato soup to be 96.4% NaCl, 2.0% CaCl$_2$, and 1.6% KCl. Additional salt blends could be created to continue to reduce NaCl and increase the concentrations of the other two salts, for further potential health benefits, without significantly impacting predicted acceptance scores. This study demonstrates the potential for mixture design analysis, along with sensory evaluation and electronic tongue analysis, to aid in achieving salt reduction targets in food products.
Table 1. Salt mixture design for both solutions and soups to obtain a mixture closest to the target established as 93mM NaCl.

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>70 mM NaCl (%)</th>
<th>70mM KCl (%)</th>
<th>22mM CaCl₂ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NaCl</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>KCl</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>CaCl₂</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Center</td>
<td>33.33</td>
<td>33.33</td>
</tr>
<tr>
<td>5</td>
<td>NaCa</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>NaK</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>KCa</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>CaDom&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.67</td>
<td>16.67</td>
</tr>
<tr>
<td>9</td>
<td>KDom</td>
<td>16.67</td>
<td>66.67</td>
</tr>
<tr>
<td>10</td>
<td>NaDom</td>
<td>66.67</td>
<td>16.67</td>
</tr>
</tbody>
</table>

<sup>a</sup>Dom: Dominant indicates the presence of 66.67% of the named salt in the mixture.
Table 2. Tomato soup treatment names and formulations for the panel with orientation (n = 30).

<table>
<thead>
<tr>
<th>Treatment Name</th>
<th>Vegetables (g)</th>
<th>Herbs (g)</th>
<th>Other (g)</th>
<th>Salt (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carrot</td>
<td>Celery</td>
<td>Onion</td>
<td>Oregano</td>
</tr>
<tr>
<td>NaCl</td>
<td>49.70</td>
<td>49.70</td>
<td>49.70</td>
<td>0.3</td>
</tr>
<tr>
<td>KCl</td>
<td>49.65</td>
<td>49.65</td>
<td>49.65</td>
<td>0.3</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>49.74</td>
<td>49.74</td>
<td>49.74</td>
<td>0.3</td>
</tr>
<tr>
<td>Center</td>
<td>49.70</td>
<td>49.70</td>
<td>49.70</td>
<td>0.3</td>
</tr>
<tr>
<td>NaCa</td>
<td>49.72</td>
<td>49.72</td>
<td>49.72</td>
<td>0.3</td>
</tr>
<tr>
<td>NaK</td>
<td>49.68</td>
<td>49.68</td>
<td>49.68</td>
<td>0.3</td>
</tr>
<tr>
<td>KCa</td>
<td>49.70</td>
<td>49.70</td>
<td>49.70</td>
<td>0.3</td>
</tr>
<tr>
<td>CaDomᵇ</td>
<td>49.72</td>
<td>49.72</td>
<td>49.72</td>
<td>0.3</td>
</tr>
<tr>
<td>KDom</td>
<td>49.67</td>
<td>49.67</td>
<td>49.67</td>
<td>0.3</td>
</tr>
<tr>
<td>NaDom</td>
<td>49.70</td>
<td>49.70</td>
<td>49.70</td>
<td>0.3</td>
</tr>
<tr>
<td>Target</td>
<td>49.64</td>
<td>49.64</td>
<td>49.64</td>
<td>0.3</td>
</tr>
</tbody>
</table>

*aAll vegetables were weighed to ±0.05 g, all herbs, excluding marjoram (±0.05 g), to ±0.01 g, and the tomato sauce, water, and salts all were weighed to ±0.01 g*

*bDom: Dominant indicates the presence of 66.67% of the named salt in the mixture.*
**Table 3.** Degrees of freedom and $F$-values for the sensory panel with orientation (n = 30) examining the influence of treatment (T), panelist (P) and the interaction between these two. A * represents a significant difference at $p \leq 0.05$.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Salt</th>
<th>Sweet</th>
<th>Sour</th>
<th>Bitter</th>
<th>Umami</th>
<th>Metallic</th>
<th>Drying</th>
<th>Other</th>
<th>Salt</th>
<th>Sweet</th>
<th>Sour</th>
<th>Bitter</th>
<th>Umami</th>
<th>Metallic</th>
<th>Drying</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>10</td>
<td>210.8*</td>
<td>4.0*</td>
<td>1.5</td>
<td>45.4*</td>
<td>2.2*</td>
<td>10.8*</td>
<td>3.2*</td>
<td>8.7*</td>
<td>9.5*</td>
<td>2.3*</td>
<td>0.8</td>
<td>5.6*</td>
<td>2.7*</td>
<td>2.6*</td>
<td>2.5*</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>29</td>
<td>24.9*</td>
<td>8.2*</td>
<td>33.4*</td>
<td>14.6*</td>
<td>28.6*</td>
<td>32.9*</td>
<td>19.1*</td>
<td>27.3*</td>
<td>13.0*</td>
<td>9.0*</td>
<td>7.1*</td>
<td>20.3*</td>
<td>29.9*</td>
<td>41.6*</td>
<td>38.0*</td>
<td>23.5*</td>
</tr>
<tr>
<td>T*P</td>
<td>290</td>
<td>5.5*</td>
<td>1.2</td>
<td>2.3*</td>
<td>1.5</td>
<td>2.5*</td>
<td>1.8*</td>
<td>1.9*</td>
<td>1.3</td>
<td>0.9</td>
<td>0.5</td>
<td>1.1</td>
<td>1.3</td>
<td>1.2</td>
<td>2.1*</td>
<td>1.7*</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Mean intensity values for sensory properties of solutions and soups as determined by the panel with orientation (n = 30). Different letters in the same column indicate significant differences between treatments as analyzed by Tukey’s HSD (p ≤ 0.05). The panel with orientation used a labeled magnitude scale anchored by “no sensation” at the bottom and “strongest imaginable” at the top. Although not displayed to the panelists, these anchors were at 0 and 2 along the scale, with roughly logarithmic spacing along the scale.

<table>
<thead>
<tr>
<th></th>
<th>Solutions</th>
<th></th>
<th>Soups</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Salt</td>
<td>Sweet</td>
<td>Sour</td>
<td>Bitter</td>
</tr>
<tr>
<td>T&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td>1.4b</td>
<td>0.6a</td>
<td>0.5a</td>
<td>0.5cd</td>
</tr>
<tr>
<td>KCl</td>
<td>0.9de</td>
<td>0.4ab</td>
<td>0.5a</td>
<td>1.2a</td>
</tr>
<tr>
<td>CaCl&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.3g</td>
<td>0.2b</td>
<td>0.4a</td>
<td>0.7a</td>
</tr>
<tr>
<td>Center</td>
<td>0.7ef</td>
<td>0.4ab</td>
<td>0.5a</td>
<td>0.7bc</td>
</tr>
<tr>
<td>NaCa</td>
<td>0.9d</td>
<td>0.4ab</td>
<td>0.5a</td>
<td>0.7bc</td>
</tr>
<tr>
<td>NaK</td>
<td>1.1c</td>
<td>0.5ab</td>
<td>0.4a</td>
<td>0.7c</td>
</tr>
<tr>
<td>KCa</td>
<td>0.6f</td>
<td>0.3b</td>
<td>0.4a</td>
<td>0.7a</td>
</tr>
<tr>
<td>CaDom&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.6f</td>
<td>0.3ab</td>
<td>0.4a</td>
<td>0.9b</td>
</tr>
<tr>
<td>KDom&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.8de</td>
<td>0.4ab</td>
<td>0.4a</td>
<td>1.0b</td>
</tr>
<tr>
<td>NaDom&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.3bc</td>
<td>0.6a</td>
<td>0.5a</td>
<td>0.6cd</td>
</tr>
<tr>
<td>Target</td>
<td>1.5a</td>
<td>0.5ab</td>
<td>0.4a</td>
<td>0.4d</td>
</tr>
</tbody>
</table>

<sup>a</sup>T-Treatment
<sup>b</sup>Dom: Dominant indicates the presence of 66.67% of the named salt in the mixture.
**Table 5.** Consumer liking mean separations for solutions (n = 94) and tomato soups (n = 100). Different letters in the same column indicate significant differences between treatments as analyzed by Tukey’s HSD (p ≤ 0.05).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Salt</th>
<th>Sweet</th>
<th>Sour</th>
<th>Bitter</th>
<th>Umami</th>
<th>Overall</th>
<th>Salt</th>
<th>Sweet</th>
<th>Sour</th>
<th>Bitter</th>
<th>Umami</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>6.0ab</td>
<td>5.4a</td>
<td>5.4a</td>
<td>5.3ab</td>
<td>5.7a</td>
<td>5.6ab</td>
<td>6.3a</td>
<td>6.3ab</td>
<td>5.9ab</td>
<td>5.8a</td>
<td>6.4ab</td>
<td>6.4ab</td>
</tr>
<tr>
<td>KCl</td>
<td>4.0cde</td>
<td>4.1d</td>
<td>3.6e</td>
<td>2.9f</td>
<td>3.8e</td>
<td>2.9d</td>
<td>5.1de</td>
<td>5.0f</td>
<td>5.0de</td>
<td>4.4f</td>
<td>5.4def</td>
<td>4.7f</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>3.7e</td>
<td>4.0d</td>
<td>3.8e</td>
<td>3.0f</td>
<td>3.9e</td>
<td>2.9d</td>
<td>5.1e</td>
<td>5.1ef</td>
<td>4.6e</td>
<td>4.4f</td>
<td>5.3ef</td>
<td>4.5f</td>
</tr>
<tr>
<td>Center</td>
<td>4.7c</td>
<td>4.8bc</td>
<td>4.5bc</td>
<td>4.2cd</td>
<td>4.5cd</td>
<td>4.2c</td>
<td>5.6cde</td>
<td>5.8bcd</td>
<td>5.4bcd</td>
<td>5.1cde</td>
<td>5.9bcd</td>
<td>5.7cde</td>
</tr>
<tr>
<td>NaCa</td>
<td>5.5b</td>
<td>5.3ab</td>
<td>5.0ab</td>
<td>4.8bc</td>
<td>5.1bc</td>
<td>4.9b</td>
<td>6.0abc</td>
<td>5.8bcd</td>
<td>5.5a-d</td>
<td>5.2b-e</td>
<td>5.8cd</td>
<td>5.8bcd</td>
</tr>
<tr>
<td>NaK</td>
<td>5.5b</td>
<td>5.4ab</td>
<td>5.1a</td>
<td>4.9ab</td>
<td>5.1bc</td>
<td>5.1b</td>
<td>5.6cde</td>
<td>5.6cde</td>
<td>5.5a-d</td>
<td>5.3a-d</td>
<td>5.7cde</td>
<td>5.8bcd</td>
</tr>
<tr>
<td>KCa</td>
<td>3.9e</td>
<td>4.0d</td>
<td>3.7e</td>
<td>3.3ef</td>
<td>3.8e</td>
<td>2.9d</td>
<td>5.1de</td>
<td>5.1f</td>
<td>4.8e</td>
<td>4.4f</td>
<td>5.2f</td>
<td>4.6f</td>
</tr>
<tr>
<td>CaDom²</td>
<td>4.0de</td>
<td>4.2d</td>
<td>3.9de</td>
<td>3.4ef</td>
<td>4.0de</td>
<td>3.1d</td>
<td>5.2de</td>
<td>5.6cde</td>
<td>5.1cde</td>
<td>4.8def</td>
<td>5.7cde</td>
<td>5.3de</td>
</tr>
<tr>
<td>KDom</td>
<td>4.7cd</td>
<td>4.4cd</td>
<td>4.5cd</td>
<td>3.8de</td>
<td>4.3de</td>
<td>3.9c</td>
<td>5.7bcd</td>
<td>5.5def</td>
<td>5.2cde</td>
<td>4.7ef</td>
<td>5.7c-f</td>
<td>5.1ef</td>
</tr>
<tr>
<td>NaDom</td>
<td>6.3a</td>
<td>5.7a</td>
<td>5.5a</td>
<td>5.3ab</td>
<td>5.6ab</td>
<td>6.0a</td>
<td>6.2ab</td>
<td>6.1abc</td>
<td>5.7abc</td>
<td>5.4abc</td>
<td>6.1abc</td>
<td>6.0abc</td>
</tr>
<tr>
<td>Target</td>
<td>6.0ab</td>
<td>5.6a</td>
<td>5.4a</td>
<td>5.4a</td>
<td>5.8a</td>
<td>6.0a</td>
<td>6.5a</td>
<td>6.4a</td>
<td>6.0a</td>
<td>5.7a</td>
<td>6.4a</td>
<td>6.4a</td>
</tr>
</tbody>
</table>

²Dom: Dominant indicates the presence of 66.67% of the named salt in the mixture.
Table 6. Correlation ($R^2$) values between the sensory evaluation (panel with
orientation; n=30) of salt solutions (n=12) and tomato soups (n=12) and the electronic
tongue response as analyzed using partial least square regression.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>$R^2$ Salt Solution</th>
<th>$R^2$ Tomato Soup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt</td>
<td>0.93</td>
<td>0.95</td>
</tr>
<tr>
<td>Sweet</td>
<td>0.78</td>
<td>0.90</td>
</tr>
<tr>
<td>Sour</td>
<td>0.45</td>
<td>0.55</td>
</tr>
<tr>
<td>Bitter</td>
<td>0.86</td>
<td>0.92</td>
</tr>
<tr>
<td>Umami</td>
<td>0.76</td>
<td>0.69</td>
</tr>
<tr>
<td>Metallic</td>
<td>0.58</td>
<td>0.87</td>
</tr>
<tr>
<td>Drying</td>
<td>0.82</td>
<td>0.57</td>
</tr>
</tbody>
</table>
Table 7. Tomato soups mixture design regression equations from the consumer panel data. For analysis, the most complex (special cubic) was applied first, simplifying the model if significance was not found.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>$R^2$ (adj$^a$)</th>
<th>Model</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt</td>
<td>0.84</td>
<td>Linear</td>
<td>$6.48X_1^* + 5.13X_2^* + 5.16X_3^*$</td>
</tr>
<tr>
<td>Sweet</td>
<td>0.86</td>
<td>Linear</td>
<td>$6.41X_1^* + 5.28X_2^* + 5.09X_3^*$</td>
</tr>
<tr>
<td>Sour</td>
<td>0.90</td>
<td>Linear</td>
<td>$6.04X_1^* + 4.73X_2^* + 5.00X_3^*$</td>
</tr>
<tr>
<td>Bitter</td>
<td>0.99</td>
<td>Quadratic</td>
<td>$5.73X_1^* + 4.44X_2^* + 4.34X_3^* + 0.56X_1X_2^* + 1.04X_1X_3^* + 0.25X_2X_3$</td>
</tr>
<tr>
<td>Umami</td>
<td>0.95</td>
<td>Special Cubic</td>
<td>$6.35X_1^* + 5.30X_2^* + 5.39X_3^* - 0.11X_1X_2 - 0.61X_1X_3 - 0.54X_2X_3 + 11.12X_1X_2X_3^*$</td>
</tr>
<tr>
<td>Overall</td>
<td>0.89</td>
<td>Linear</td>
<td>$6.58X_1^* + 4.76X_2^* + 4.77X_3^*$</td>
</tr>
</tbody>
</table>

$^a$Adj-Adjusts the coefficient of determination based on the number of independent variables in the model.

$X_1$ – Sodium chloride; $X_2$ – Calcium chloride; $X_3$ - Potassium chloride

Significant terms designated by *
Figure 1. PCA biplot of attributes evaluated by panel with orientation ($n = 30$) and salt solutions. The salt samples (composition described in Table 1) are indicated by a blue circle, with the target solution being defined as a 30% salt reduction solution indicated by the target image.
Figure 2. PCA biplot of attributes evaluated by panel with orientation (n = 30) and tomato soups. The soup samples (composition described in Table 1) are indicated by a blue circle, with the target solution being defined as a 30% salt reduction soup indicated by the target image.
Figure 3. PCA of salt solutions as evaluated by the electronic tongue. The sensors are indicated by umami, metallic, bitter, sweet, spicy, sour, and salty. The triangles represent triplicate measurements. Samples are in red with names indicated in Table 1.
**Figure 4.** PCA of tomato soups as evaluated by the electronic tongue. The sensors are indicated by umami, metallic, bitter, sweet, spicy, sour, and salty. The triangles represent triplicate measurements. Samples are in red with names indicated in Table 1.
Figure 5. Partial least squares correlation biplot of tomato soups and corresponding consumer liking scores and intensity ratings for attributes evaluated by panelists with orientation ($n = 30$). Refer to Table 1 for treatment names.
Figure 6. Contour plots for salt liking, sweet liking, sour liking, bitter liking, umami liking, and overall liking of tomato soups based on mixture design regression models.
Figure 7. Overlaid contour -white space is desirable region. Numbers for high and low input were selected based on target averages for the panel mean ± ½ SD of the target soup for liking of that particular attribute.
<table>
<thead>
<tr>
<th></th>
<th>Sodium</th>
<th>Calcium</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hi</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Cur</td>
<td>[0.9636]</td>
<td>[0.0199]</td>
<td>[0.0165]</td>
</tr>
<tr>
<td>Lo</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Salt
- Target: 6.50
- \( y = 6.4293 \)
- \( d = 0.90152 \)

### Sweet
- Target: 6.3650
- \( y = 6.3686 \)
- \( d = 0.99488 \)

### Sour
- Target: 5.9950
- \( y = 5.9950 \)
- \( d = 1.0000 \)

### Bitter
- Target: 5.730
- \( y = 5.7134 \)
- \( d = 0.97725 \)
Figure 8. Desirability function for tomato soups when striving to achieve the target value. The target value input was the mean values for the panel with orientation of the target soup. Lower bound was set to mean value of \( \text{target} - 0.5\text{SD} \) of target; target was set to \( \text{target soup} \) mean value, and upper bound to \( \text{target} +0.5\text{SD} \) of target. Weight and importance of each \( Y \) was set to 1.
CHAPTER IV
UTILIZING HERBS WITH MICROWAVE-ASSISTED THERMAL STERILIZATION TO ENHANCE SALTINESS PERCEPTION IN A CHICKEN PASTA MEAL

ABSTRACT
This study was the first to evaluate the influence of herb addition in a complex food matrix processed by microwave-assisted thermal sterilization (MATS) system for potential salt reduction implications. In a chicken pasta meal, salt concentrations included 100% (full salt) and reduced salt variations (75, 50 and 25% of the original salt concentration) and for each meal, a version with and without herb addition. The influence of storage time on sensory perception and acceptance was investigated, along with the odor-induced saltiness enhancement (OISE). Trained sensory panel results showed that the addition of herbs to the chicken pasta meal increased the intensity of many flavors and led to an increased saltiness perception, demonstrating their congruency with salty taste. The addition of herbs allowed for a 50% salt reduction in a processed prepared meal while maintaining the same intensity of saltiness perception as determined by a trained panel and overall meal acceptance by consumers. The OISE was only significant for the 25% salt meal (p < 0.05) suggesting that the influence of herb addition on saltiness perception at lower salt concentrations was more influential than at higher salt concentrations. Over longer storage times, meals processed by MATS and stored at ambient temperature increased in aroma, taste, and flavor intensities as
well as in acceptance of many meal attributes. The present study contributed an additional strategy of product reformulation, specifically herb addition, to the portfolio of salt-reduction strategies for prepared meals using MATS.

**PRACTICAL APPLICATION**

The addition of herbs to prepared meals (chicken pasta) may allow for up to a 50% reduction in salt content while maintaining the same saltiness intensity perception and overall consumer acceptance. This has important implications for the food industry as sodium reduction is a complex task. Furthermore, the additional herbs utilized in this study increased the intensity of certain aromas and flavors, and led to increased saltiness perception; these herbs could be considered in future salt reduction applications as this study demonstrates their congruency with salty taste.
INTRODUCTION

Sodium is an essential mineral responsible for controlling blood pressure, cell water content, and facilitating nerve impulse transition (Mills & Norton, 2013). However, high sodium intake is accompanied by an array of health concerns including increased blood pressure, risk of cardiovascular disease, stroke, and renal disease (Cook et al., 2007; Strazzullo et al., 2009; Suckling et al., 2010; Yang et al., 2011). Recent estimates report an average global salt intake of 10g/day (4g sodium) (Powles et al., 2013) while the World Health Organization (WHO) recommends a salt intake of less than 5g/day (2g sodium) (WHO, 2007). A global target of 30% sodium reduction by 2025 has been set (WHO, 2012) as sodium reduction could have the potential to be one of the most cost-effective ways of reducing the growing burden of non-communicable diseases (Neal et al., 2007).

As sodium is ubiquitous in the US food supply, with up to 75% of dietary sodium coming from processed foods (Brown et al., 2009), effective strategies are needed to decrease consumption to recommended levels. Additionally, salt has many functional properties within food, beyond taste and flavor, and these functions should be considered when creating a reduced salt product. Accordingly, many strategies have investigated ways to reduce salt and/or to increase the perception of the salty taste in foods. These strategies include gradual reduction or the ‘stealth’ approach (Bertino et al., 1982; Girgis et al., 2003), replacement by potassium chloride (Fregly, 1981; Li et al., 2008; Toldrá & Barat, 2009), salt enhancers (Segawa et al., 1995), salt-associated aromas (Lawrence et al., 2009), salt boosters (Busch et al., 2013; Dötsch et al., 2009),
encapsulation of salt crystals (Noort et al., 2012), inhomogeneous spatial distribution (Noort et al., 2010), utilizing different crystal sizes (Rama et al., 2013), the use of high pressure processing (Crehan, Troy, & Buckley, 2000; Rodrigues, Rosenthal, Tiburski, & Cruz, 2016), as well as other techniques previously described (Busch et al., 2013; Kilcast & den Ridder, 2007). However, no study to date has systematically investigated the potential for saltiness enhancement via microwave-assisted thermal sterilization (MATS) processing. The lack of research into this area is remarkable given previous observations have found MATS foods taste saltier than their counterparts processed in retorts, with preliminary observations suggesting that the salt concentration in the product could potentially be reduced by 20 to 50% to bring the saltiness to a desirable level (Tang, 2015).

While studies have demonstrated that salt reduction is possible via the ‘stealth’ method or with partial replacement of sodium chloride with potassium chloride, these approaches come with limitations in terms of consumer acceptability (Busch et al., 2013) and the tendency to be bitter and have a metallic off-taste (Murphy et al., 1981), respectively. Considering these limitations, a new salt reduction strategy is needed to continue to bring salt consumption down to recommended levels. Previous work has demonstrated aromas associated with saltiness can elicit an odor induced saltiness enhancement (OISE) (Lawrence et al., 2011, 2009; Nasri et al., 2013) in both aqueous solutions and model cheeses. The present study seeks to expand upon past research by investigating a ready-to-eat chicken pasta meal with the hypothesis that the addition of herbs into reduced salt meals results in a higher perceived intensity of salt, thus
allowing less salt to be added to the meal without a noticeable different in saltiness by consumers. Chicken pasta meals were selected for the complexity of the matrix as well as the ability to control salt levels. Additionally, this study investigated the influence of storage time on the chicken pasta meals. As commercially sterile meals may sit on the shelf for a prolonged period of time prior to consumption, understanding sensory changes that may take place during storage is important as these will likely influence consumer acceptance. The hypothesis, based on a previous study, was that there would be differences across the different salt concentrations, but these differences would decrease the longer the samples are stored due to salt equilibration within the meals (Bornhorst et al., 2016).

**MATERIALS AND METHODS**

**Materials**

Fettucine (DeCecco Fettucine no. 6; Fara San Martino [CH], Italy), chicken breasts (Safeway brand, Pleasanton, CA), sun-dried tomatoes (Tantillo, Laguna Niguel, CA), chopped frozen onions (Safeway brand), UHT whipping cream (Safeway brand), southwest chipotle seasoning blend (Mrs. Dash, Roseland, NJ), salt (Morton, Chicago, IL), dried basil (McCormick, Hunt Valley, MD), black pepper (McCormick), garlic powder (McCormick), unsalted butter (Darigold, Seattle, WA), deionized water (Milli-Q Reagent Water System, Millipore, Bedford, MA), and ThermoFlo Starch (National Starch Food Innovation, Bridgewater, NJ) were used for the preparation of the chicken pasta meals as well as for various standards for the trained panel as described in **Table 1** (taste, flavor and aroma) and **Table 2** (texture). Additional materials used as
standards for the trained panel were salt (Safeway brand), sugar (Walmart brand, Bentonville, Arkansas), MSG (Accent, Parsippany, NJ), citric acid (≥99.5%, Sigma-Aldrich, St. Louis, MO), onion powder (McCormick), reduced sodium chicken broth (Safeway brand), brown rice pasta spirals (Tinkyáda, Scarborough, Ontario, Canada), flour (Gold Medal, Minneapolis, MN), sour patch watermelons (Mondelez, East Hanover, NJ), turkey jerky (KRAVE Pure Foods Inc., Sonoma, CA), cooked chicken breasts (John Soules Foods Inc., Tyler, TX), red pepper flakes (McCormick), and heavy whipping cream (Safeway brand).

**Formulations**

The salt concentrations tested were based on a past value utilized in a commercial pasta sauce formulation with subsequent reductions to 75, 50, and 25% of the original salt concentration. Meals containing these 4 salt concentrations were prepared with and without additional herbs, resulting in a total of 8 formulations. A breakdown of sample labeling and formulations can be found in **Table 3**.

**Food Preparation Prior to MATS Processing**

Onions were weighed to 2.2 ± 0.1g in plastic soufflé cups with lids and frozen until the morning of microwave processing. Sun-dried tomatoes and chicken breasts were cut into approximately 0.5 × 1 cm and 2.5 × 1.3 ×2 cm pieces, respectively, weighed to 5.5 ± 0.1g and 76.5 ± 0.5g, respectively, in plastic soufflé cups with lids, and refrigerated until required for processing.

Sauces for the chicken pasta meals were prepared the evening prior to microwave processing (described below). First, all ingredients for the sauces were weighed: butter,
water, starch, cream, salt, Southwest chipotle seasoning, dried basil, black pepper, and garlic powder. The starch was mixed into the water to create a slurry. To melted butter, the slurry of water and starches was added, followed by the cream. The mixture was heated until it reached 82°C. The spices and salt corresponding to the sample were added. A total of 8 sauces, 1 for each of the formulations, was prepared. The ingredient amounts in each sauce in a per tray basis are described in Table 3. Sufficient sauce for 20, 310.5 ml (14cm × 9.7cm × 2.8 cm) trays of each formulation was prepared.

Twenty minutes prior to the packing of trays for microwave processing, pasta (500 g) was boiled at 100°C for 4 min in 4L of deionized water (Milli-Q Reagent Water System); this was done in 4 pots for a total of 2,000 g of pasta for each processing run of the MATS system. Pasta was drained and rinsed under cold water. While the pasta water was coming to a boil, the sauces, onions, tomatoes, and chicken were pulled out of the refrigerator/ freezer to bring to 22°C. 310.5 ml trays made of polypropylene and EVOH (Printpack, Atlanta, Ga., U.S.A.) were filled in this sequence; blanched noodles (78.0 ± 0.3 g), chicken (76.5 ± 0.5 g), onions (2.2 ± 0.1 g), tomatoes (5.50 ± 0.1 g), and prepared sauce (137.8 ± 0.2 g) for a total of 300 g in each tray. The trays were sealed, with a lid film made of outer barrier of polyethylene terephthalate and inner layer of polypropylene with multiple layers in between (Printpack), using a MULTIVAC T 200 (MULTIVAC, Kansas City, MO) at 200°C for 4s under a vacuum of 65mbar.

MATS Processing of Meals

The pilot scale microwave assisted thermal sterilization (MATS) system at Washington State University with four sections, preheating, microwave heating,
holding, and cooling, was used for this study. This MATS system has described previously in depth (Resurreccion et al., 2013). The sterilization process for this study followed a processing schedule determined by preliminary studies to identify a processing schedule that would result in the process lethality ($F_0$) value of greater than 6 min (Tang et al., 2008). From this preliminary testing, the different salt concentrations were found to influence the dielectric properties to an extent that each salt concentration needed to be processed in its own batch through the MATS system to obtain similar $F_0$ values. All meals were preheated for 30 min in 61°C water and cooled for 5 min in a 61°C water bath. Microwave heating and holding times varied depending on the salt concentration and are described in Table 4. These varied processing times resulted in similar $F_0$ values. $F_0$ was determined using the formula below with data from the temperature measurements coming from mobile metallic sensors and data logging software (TMI-USA, Inc., Reston, VA) (Luan, Tang, Pedrow, Liu, & Tang, 2013).

$$F_0 = \int_0^T \frac{(T - T_r)}{z} dt$$

where $T$ is the measured temperature (°C); $T_r$ is the reference temperature (121.1°C); $z$ has a value of 10°C for sterilization; and $t$ is the heating time (min).

**Microbial Testing**

After samples were processed by the MATS system, and prior to sensory testing, meals were subjected to microbial testing to confirm they were safe for human consumption. At each time point, meals were tested for aerobic count, yeast & mold, total coliforms, *B. cereus*, *Salmonella* spp., *L. monocytogenes*, and *E. coli* 0157:H7 by
AOAC methods, except for *B. cereus* which was tested by the FDA/BAM Chapter 14 method (Micro-Chem Laboratories, INC. in Seattle, WA).

**Trained Sensory Evaluation Panel**

A trained sensory evaluation panel (n=10) was conducted at WSU School of Food Science Sensory Lab in Pullman, WA to evaluate the sensory properties of the chicken pasta meals prepared via the MATS system. Prior to participation, all trained panelists signed a consent form that was approved by the WSU Institutional Review Board for the use of human subjects. Electronic advertisements were utilized to recruit panelists based on their interest in evaluating prepared meals. Throughout the course of the study minimal information about the sample preparation was provided to panelists to reduce the introduction of bias. A non-monetary incentive was provided to the trained panelists for their participation in the study.

Aroma, taste, flavor, texture, and mouthfeel attributes that best characterized the different chicken pasta meals were determined by the panel leader using previous literature as a reference and based on feedback from the panel. Panelists received 12 hours of training. During the first sessions, the panel leader presented suggested standards for each attribute, and then, with feedback from the panel, altered those that did not fit the chicken pasta meal examples. The complete list of attributes, definitions, and reference standards are outlined in Table 1 (aroma, taste and flavor) and Table 2 (texture). Panelists assessed the intensity of each attribute on a 15-cm line scale anchored by “low” and “high” at 1.5 cm and 13.5 cm, respectively. After each session, panelists were provided overall feedback from the previous day of training on their
discrimination among different samples, their repeatability among replicate samples, and their consistency with the group through analysis completed with the use of SenPAQ version 6.03 (Qi Statistics, Berkshire, UK). Additionally, panelists received their ratings versus the group ratings on each evaluated attribute from the previous day of training. As training progressed, panelists were introduced to the sensory booths and evaluation software (Compusense 5, Release 5.0, Guelph, ON, Canada) with practice evaluation sessions. The use of the evaluation software allowed for Feedback Calibration Method (FCM) during the final training sessions to provide panelists with instant feedback on each attribute. FCM has been demonstrated to produce higher, more reliable results in less time than traditional descriptive analysis training (Findlay, Castura, & Lesschaeve, 2007).

Formal evaluations for the chicken pasta meals followed the training sessions. Evaluations took place in individual sensory booths under white lighting. The formal evaluations took place twice a week at 6 storage times: 0 days, 7 days, 14 days, 21 days, 183 days, and 365 days post-meal processing in the MATS. These storage times were selected to represent meal properties immediately following processing and the possible evolution of sensory properties over time. More shorter storage times were investigated (ie. at the beginning of the study) to investigate how salt diffusion may influence meal perception, as it has been suggested to wait 14 days to perform sensory testing in multicomponent food products that have undergone MATS processing, or other less sever heat treatments, due to salt equilibration (Bornhorst et al., 2016).
At each time point (n=6), panelists received each of the 8 chicken pasta meals. The second day in the week allowed for the replication of each sample to be tested. Testing order was randomized and each sample (~25 g) was served in a 4 oz soufflé cup with a lid and labelled with a random 3-digit code. Samples were warmed in their trays under a food warmer (Hatco Corporation, Milwaukee, WI) set at high heat for 30 min, 15 min on one side, then 15 min flipped on the other side. The trays were cut open, and the ~300g of food was equally distributed among 12 soufflé cups with lids. These cups were then placed back under the food warmer, at heat setting 5.5, until they were served to the trained panelists. In each session, there was a 1 min break between each sample and a 15-min break after the first 4 samples. During these breaks, panelists were instructed to use the provided unsalted crackers and Milli-Q water for palate cleansing. Additionally, panelists were instructed to refrain from eating, drinking, or smoking for at least 30 min prior to evaluations.

**Consumer Panel**

Consumers (183 days: n = 93; 365 days: n = 72) were recruited from the Washington State University community through email to the listserv from Compusense scheduling software. Prior to participation, all consumers signed a consent form that was approved by the WSU Institutional Review Board for the use of human subjects. For panel 1 (183 days of storage at 17°C), the panel consisted of 60 females and 33 males between the ages of 20 and 76, with an average age of 39. For panel 2 (365 days of storage at 17°C), the panel consisted of 45 females and 27 males between the ages of 22 and 88, with an average age of 41. To reduce bias, consumers who previously
participated in the trained sensory evaluation panel did not participate in the consumer panel. Evaluations were conducted under white lights in individual sensory booths. Sample presentation was the same as for the trained panel, but instead of tasting 8 different samples, consumers only evaluated 4 formulations - the 100 and 50% salt formulations with and without herbs. Consumers evaluated the chicken pasta meals on a 9-point hedonic scale (where 1 = dislike extremely and 9= like extremely) for their acceptance of aroma, appearance, salt, umami, flavor, pasta texture, chicken texture, and overall acceptance. Comments were also collected.

Statistical Analysis

Trained panel data was analyzed using a 3-way ANOVA using XLSTAT (version 2017.01; Addinsoft, Paris, France). Using this model, the sensory attributes were considered the dependent variables while the independent variables included sample, storage time, panelist and replicate; appropriate interactions were also included in the model. Means were compared using Tukey’s HSD test. Additionally, sensory data were analyzed using Principal Components Analysis (PCA) to visualize differences among the samples. To further investigate the potential impact of herbs on saltiness perception, odor induced saltiness enhancement (OISE) values were calculated for each salt concentration tested. For each panelist, the OISE corresponded to the difference between the saltiness of the chicken pasta meal with herbs and the saltiness of the chicken pasta meal with no herbs containing the same amount of sodium chloride, averaged over replicates (Lawrence et al., 2009). OISE significance was determined using Student’s t-tests to assess whether the OISE means were different from zero.
Consumer data were analyzed with ANOVA using XLSTAT and appropriate interactions were included in the model. Chicken pasta meals evaluated by both panels were further analyzed by a partial least squares correlation biplot (XLSTAT). For all data analyses, effects were considered to be significant when \( p < 0.05 \).

**RESULTS AND DISCUSSION**

*Microbial Testing Results*

Prior to sensory testing, microbial testing was performed to ensure a safe product. At each storage time, microbial testing was negative for *Salmonella* spp., *L. monocytogenes*, and *E. coli* 0157:H7. The aerobic count was < 20 CFU per gram of sample, total coliform and *B. cereus* were < 10 CFU per gram of sample, and yeast & mold was < 100 CFU per gram of sample at each storage time. These microbiological counts suggested the product was safe for sensory evaluation.

*Trained sensory evaluation panel results across treatments*

The influence of different factors on the aroma, flavor and taste attributes of the meals are shown in Table 5 while influences of these attributes on meal texture and mouthfeel attributes are presented in Table 6. Panelist and replication effects may be attributed to palate fatigue, complexity of certain attributes, and limited training time. However it has been demonstrated that only limited training, as short as 4 hours, may be necessary to find many texture and flavor differences (Chambers et al., 2004). Even with the panelist effects, panelists could distinguish among the samples.

To further see how the different samples influenced the intensity ratings of aroma, flavor and taste attributes, intensity values are presented in Table 7. At 100%,
75%, and 25% salt, meals containing herbs were perceived as saltier than meals containing no additional herbs at the same salt concentrations. Thus, the addition of herbs enhanced the perceived intensity of salt at these salt concentrations. It is noteworthy that the 25% salt meal containing herbs was not significantly different in saltiness intensity perception from the 75% salt meal containing no additional herbs. Hence, the addition of herbs to the chicken pasta meals allowed for a 50% reduction in salt content while maintaining the same saltiness intensity perception. The influence of salt concentration and herb addition were teased apart and analyzed; this analysis confirmed these results.

As previously suggested, sourness can include a salty dimension (Wise & Breslin, 2011). Previous work has demonstrated that in ternary odor-sour-salty solutions, the sourness enhanced saltiness perception when a salt-related odor (i.e. sardine aroma) was present (Nasri et al., 2013). Thus, it is interesting to note that in the present study, all meals with herb addition had a higher perceived intensity of sourness than meals containing no additional herbs (Table 7). In this complex matrix, the increased sourness perception in the meals with herbs may be contributing to the enhanced saltiness perception. Additionally, salt intensity was positively correlated with sourness intensity ($p < 0.0001; r = 0.36$), further supporting the synergistic potential of sourness and saltiness in a chicken pasta meal. Umami intensity was also positively correlated with salt intensity ($p < 0.0001; r = 0.29$). The perceived intensity of umami was significantly lower in the meals with no additional herbs than in those with additional herbs at the same salt concentration (Table 7). The increase in umami perception
contributed via the herbs may also be contributing to the enhanced saltiness intensity perception as umami can act synergistically to enhance salt taste (Kemp & Beauchamp, 1994). The perception of sweetness was only significantly different between the 50H and 100N, with 100N being perceived as sweeter. The interactions between saltiness and sweetness vary by concentration and at lower concentrations, saltiness can enhance sweetness (Keast & Breslin, 2003).

Many aroma and flavor intensities, spice, tomato, onion, and garlic, were higher in the meals containing herbs versus the meals containing no additional herbs. The reverse was true for buttery aroma, buttery flavor, and dairy flavor, whereby the meals with no additional herbs were perceived as more intense in these attributes. Odor-taste congruency, the concept that an odor should be associated with a specific taste to enhance it, has been demonstrated to be a critical factor for enhancement (Lawrence et al., 2009). The additional herbs utilized in this study increased certain aromas and flavors and led to increased saltiness perception. Thus, these herbs could be considered in future salt reduction applications as the present study demonstrated their congruency with salty taste.

“Salting out” is the effect of increased flavor release due to interactions between salt ions and water which reduces the availability of water to solubilize the flavor compounds (Rabe, Krings, & Berger, 2003). The “salting out” effect of certain aroma compounds is a common occurrence (Mitchell, Brunton, & Wilkinson, 2011b). However, this effect was not observed within the present study, as the higher salt concentrations did not result in higher aroma intensities. The lack of finding the “salting out” effect in
this study may be due to the salt concentrations not being different enough for the panelists to observe this effect, or the possibility that the profiled aromas were not actually increased with increasing salt, as some flavor compounds have been found to be more abundant in lower salt soups (Mitchell et al., 2011b).

Fewer significant differences existed among the meals with regards to texture and mouthfeel attributes (Table 8). Indeed, no significant differences were seen among any of the chicken texture attributes among samples with herbs and no additional herbs. For pasta chewiness and crumbliness, no differences were observed. For pasta firmness, the only significant difference was between the 100H and the 50H and 25N samples, with the 100H being perceived as firmer than the 50H and 25N samples. Starchiness of pasta varied among samples with a trend for the lower salt meals with no additional herbs, to be higher in starchiness intensity than the meals with additional herbs. The limited number of differences found in the texture attributes among the chicken pasta meals may be due to the narrow range of salt concentrations utilized, 0.09-0.36% salt. Past studies that have found an influence of salt on texture required larger salt differences, such as 0.5-2.5%, in cheeses (Murtaza et al., 2014), and 0-6% salt in a meat marinade (Aktaş & Kaya, 2001). For mouthfeel attributes, heat was higher in the meals with additional herbs than the meals with no additional herbs. Creamy mouthfeel displayed the opposite trend, where the meals with no additional herbs were perceived as more intense. Fatty mouthcoating was not different between samples containing the same salt concentrations. These differences in mouthfeel may be attributed to the herb addition, particularly the addition of the southwest chipotle seasoning blend (Mrs. Dash®), as
this herb contains cayenne pepper, the spice used to create the heat mouthfeel standard. Likewise, cayenne pepper is high in the compound capsaicin (Peter, 2012) which interacts with fat whereby higher fat levels generally reduce overall heat intensity (Baron & Penfield, 1996). Thus, in the present study the fat in the samples with herbs may cause a reduction in the burning sensation and not contribute to the creamy mouthfeel as it may for samples without additional herbs.

Trained Sensory Evaluation Panel Results Across Storage Time

Chicken pasta meals experienced changes over their storage time (Figure 1). PCA of the attributes explained 74.44% of the variation among the storage times, with 44.91% and 29.53% explained by PC1 and PC2, respectively. In general, a decrease in the intensities of aroma, flavor, and taste attributes were observed over the first three weeks of storage which may be due to aroma and flavor change via oxidative degradation of spices (Catauro & Perchonok, 2012) or due to diffusion within the multiphase food product from the liquid to the solid (Bornhorst et al., 2016). The increase in some aroma, taste, and flavor intensities observed at 183 days and 365 days may be attributed to potential water migration from the package (Zhang, Tang, Rasco, Tang, & Sablani, 2016), leaving the sample more concentrated at the later storage times. Texture and mouthfeel attributes also varied across storage time (Figure 1). In general, the pasta was the highest in crumbliness at 365 days of storage, moisture release of the chicken decreased over time, and the chicken was the highest in hardness at day 365 of storage. Heat did not change over time (p > 0.05; Tukey mean separation), while both fatty mouthcoating and creamy attributes decreased in intensity over time. The changes
observed with texture and mouthfeel attributes can best be explained by moisture migration (Zhang et al., 2016), which was found to be the main mechanism of quality loss in a multicomponent food, tuna noodle casserole (Catauro & Perchonok, 2012).

PCA of the significant attributes from the ANOVA, excluding aromas due to overlap, explained 99.66% of the variation among the chicken pasta meals, with 97.17% and 2.49% explained by PC1 and PC2, respectively (Figure 2). PC1 was defined by the positively loaded attributes of spice, heat, onion, garlic, tomato, and sour, in contrast to the negatively loaded attributes of dairy, buttery, creamy, fatty, and sweet. PC2 was associated with the contrasting relationships of salt, firmness, and springiness with starchiness. Separation between chicken pasta meals was observed. Chicken pasta meals with additional herbs had higher associations with positively loaded attributes on PC1 while chicken pasta meals with no additional herbs had higher associations with negatively loaded attributes on PC1. In general, as the salt concentrations increased in the meals, they were perceived as having a higher intensity of salt, firmness, and springiness. As the salt concentrations decreased, the meals were perceived as having a higher intensity of starchiness.

To further investigate the increase in perceived saltiness when adding herbs to the chicken pasta meals, the odor induced saltiness enhancement (OISE) was calculated as discussed above. Figure 3 shows the OISE of the varying salt concentrations, collapsed over storage times 0, 7, 14, and 21 days as saltiness perception did not vary by these storage times (Table 9). The only salt concentration found to have a significant OISE, a mean different from 0 determined with Student’s t-tests, was 25% salt. This
finding is congruent with results from Nasri et al. (2011) where OISE depended on salt concentration, such that the OISE for sardine aroma in solution decreased with increasing salt concentration, from 0.01M (0.058% salt), to 0.02M (0.12% salt), and finally to 0.04M (0.23% salt); thus in a similar range of salt concentrations as represented by the current study (0.09-0.36% salt).

*Consumer Panel*

Hedonic evaluation of the chicken pasta meals by consumers resulted in differential acceptance across meals for all evaluated attributes except pasta texture and chicken texture attributes (*Table 9*). For aroma and appearance, consumers preferred meals with herbs in comparison to those without additional herbs. The addition of herbs to the 100% salt concentration did not significantly influence the saltiness acceptance; however, their addition significantly increased the acceptance of saltiness at the 50% salt concentration. This result is in alignment with the trained panel results in this study, and previous work, that demonstrated the OISE is dependent upon salt concentration and is more pronounced at lower salt concentrations in an aqueous solution (Nasri et al., 2011). Flavor and overall acceptance of meals revealed the same differences among samples, with the 100H being liked the most, 50N the least, and the 50H and 100N in between, but not different from one another. This is noteworthy as even though the 50% reduction in salt resulted in a lower saltiness acceptance, the flavor and overall acceptance of the sample was maintained. Thus, one could use this combination of herbs to reduce salt up to 50% while maintaining flavor and overall meal acceptance.
The chicken pasta meals were evaluated by consumers at both 183 days and 365 days post-processing (Figure 4). Storage times prior to 6 months were excluded to ensure salt equilibration was complete before collecting consumer acceptance data. The acceptance of saltiness, pasta texture, chicken texture, mouthfeel, and overall acceptance did not vary by storage time (p > 0.05). However, the acceptance of aroma, appearance, umami intensity, and flavor increased from 183 to 365 days (p ≤ 0.05). While perhaps contrary to initial reasoning, upon further investigation this increase in acceptance aligns with the increased intensities perceived by the trained panel as well as the hypothesis that these increased intensities were a result of moisture migration (Zhang et al., 2016). Moisture migration would have resulted in the concentration of aroma and flavor within the samples, which was viewed as more favorable by the consumer.

To investigate the relationships between the trained and consumer panel evaluation of the chicken pasta meals, a partial least squares (PLS) correlation biplot is presented in Figure 5. Higher perceived intensities of salt by the trained panel were related to higher acceptance of the salt, flavor, umami, mouthfeel, and overall attributes evaluated by the consumer panel; the acceptance of these attributes was close to the 100H sample. Higher perceived intensities of tomato, heat, garlic, spice, and onion by the trained panel were related to higher acceptance of appearance and aroma by the consumer panel, and these attributes were close to the 50H sample. The 100N and 50N samples were further from the acceptance attributes, and closer to higher perceived intensities of creamy, dairy, and buttery. Overall, the PLS biplot demonstrates the
higher perceived intensities of salt and flavors in the 100H and 50H samples were related to higher acceptance of these meals. This further demonstrates that the addition of herbs may be a potential valuable tool when reformulating products to reach salt reduction targets.

**CONCLUSION**

To conclude, this study demonstrated that OISE via the combination strategy of herb addition to meals processed by MATS can be an effective strategy for salt reduction in a ready-to-eat chicken pasta meal. Indeed, with the utilization of MATS technology to maintain flavor, and the addition of herbs to a chicken pasta meal, a 50% reduction in salt was obtained while maintaining the same saltiness intensity perception. Furthermore, consumer acceptance of flavor and overall meal acceptance was maintained when salt was reduced by 50% with the addition of herbs. A significant OISE was induced by the herbs utilized in this study at lower salt concentrations; the OISE potential of these herbs could be investigated in future food matrices.

Over longer storage times, meals processed by MATS and stored at ambient temperature may increase in aroma, taste, and flavor intensities as well as in acceptance of many meal attributes. The present study contributes to the current literature as it investigated a prepared, ready to eat meal, a food product with potential salt reduction implications for the food industry.
Table 1. Attribute definitions and standard recipes for taste, flavor, and aroma attributes used for evaluation of ready to eat chicken pasta meals by the trained sensory evaluation panel.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Standard Recipe¹,²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Taste</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>Taste on tongue stimulated by sodium salt, especially sodium chloride</td>
<td>0.45% (w/v) sodium chloride in water (1)</td>
</tr>
<tr>
<td>Sweet</td>
<td>Taste on the tongue stimulated by sugars and high potency sweeteners</td>
<td>1.6% (w/v) sucrose in water (1)</td>
</tr>
<tr>
<td>Umami</td>
<td>Flat, salty, somewhat brothy; the taste of glutamate, salts of amino acids, and other molecules called nucleotides</td>
<td>0.1% (w/v) MSG in water (2)</td>
</tr>
<tr>
<td>Sour</td>
<td>Basic taste on tongue stimulated by acid</td>
<td>0.075% (w/v) citric acid in water (1)</td>
</tr>
<tr>
<td><strong>Flavor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spice blend/</td>
<td>Aromatics of a group of spices or herbs perceived in a product that cannot be individually identified</td>
<td>Add mix of spices to 400 mL water and let stand 30 min at room temperature, filter (1)</td>
</tr>
<tr>
<td>seasoning complex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tomato</td>
<td>Aromatic associated with cooked tomato</td>
<td>Place sun-dried tomatoes at 1.2-1.4g/ 2 oz. container, cover (1)</td>
</tr>
<tr>
<td>Onion, cooked</td>
<td>Aromatic associated with onion</td>
<td>Add 1 g onion powder to 400 mL water and let stand 30 min at room temperature, filter (1)</td>
</tr>
<tr>
<td>Garlic, Dehydrated</td>
<td>Sweet, pungent, browned aromatics associated with dehydrated garlic</td>
<td>Add 1 g garlic powder to 400 mL water and let stand 30 min at room temperature, filter (1)</td>
</tr>
<tr>
<td>Brothy/ Broth-like</td>
<td>Aromatic/ taste sensation associated with boiled meat, soup, stock. Weak meaty note</td>
<td>Chicken broth to water in a 2:1 ratio (1,3)</td>
</tr>
<tr>
<td>Buttery</td>
<td>Aromatic associated with fresh butterfat, sweet cream</td>
<td>Darigold butter, 2-2.4 g/ 2 oz. container, place in sealed container (1)</td>
</tr>
<tr>
<td>Creamy/ Dairy</td>
<td>A sweet, dairy note associated with cream or other high fat dairy products</td>
<td>Room temperature fluid whipping cream, not whipped (1)</td>
</tr>
<tr>
<td><strong>Aroma</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spice blend/</td>
<td>Aromatics of a group of spices or herbs perceived in a product that cannot be individually identified</td>
<td>Add mix of spices to 400 mL water and let stand 30 min at room temperature, filter (1)</td>
</tr>
<tr>
<td>seasoning complex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tomato</td>
<td>Aromatic associated with cooked tomato</td>
<td>Place sun-dried tomatoes, 1.2-1.4g/ 2 oz. container, cover (1)</td>
</tr>
<tr>
<td>Ingredient</td>
<td>Description</td>
<td>Preparation</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Onion, cooked</td>
<td>Aromatic associated with onion</td>
<td>Add 0.50 g onion powder to 400 mL water and let stand 30 min at room temperature, filter (1)</td>
</tr>
<tr>
<td>Garlic, Dehydrated</td>
<td>Sweet, pungent, browned aromatics associated with dehydrated garlic</td>
<td>Add 1 g garlic powder to 400 mL water and let stand 30 min at room temperature, filter (1)</td>
</tr>
<tr>
<td>Brothy/ Broth-like</td>
<td>Aromatic/ taste sensation associated with boiled meat, soup, stock. Weak meaty note</td>
<td>Chicken broth to water in a 2:1 ratio (1,3)</td>
</tr>
<tr>
<td>Buttery</td>
<td>Aromatic associated with fresh butterfat, sweet cream</td>
<td>Darigold butter, 2-2.4 g/ 2 oz. container, place in sealed container (1)</td>
</tr>
</tbody>
</table>

1 All standards set at an intensity of 10 along a 15-cm line scale as defined by the trained panelists (n=11).
2 Numbers in parentheses correspond to: 1- ( Civille & Lyon, 1996); 2- (Adhikari et al., 2011); 3- (Jones, 2015); 4- (Hong Zhuang, Savage, Kays, & Himmelsbach, 2007); 5- (Weenen, Van Gemert, Van Doorn, Dijksterhuis, & De Wijk, 2003).
Table 2. Attribute definitions and standard recipe for pasta texture, chicken texture, and mouthfeel attributes used for evaluation of ready to eat chicken pasta meals by the trained sensory evaluation panel.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Definition</th>
<th>Standard Recipe¹,²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Texture (Pasta)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firmness</td>
<td>Force required to bite completely through the sample</td>
<td>DeCecco brand fettuccine cooked 3 min (3)</td>
</tr>
<tr>
<td>Chewiness</td>
<td>The number of chews required to reduce the sample to a state ready for swallowing</td>
<td>DeCecco brand fettuccine cooked 15 min, then microwaved 1.5 min (3)</td>
</tr>
<tr>
<td>Crumbliness</td>
<td>The extent to which the product crumbles when chewed, resulting in a grainy sensation in the mouth</td>
<td>Gluten free brown rice spirals cooked 16 min refrigerated 1 day (3)</td>
</tr>
<tr>
<td>Starchiness</td>
<td>The release of starch during the chewing of pasta, resulting in a chalky mouthfeel</td>
<td>70g Gold Medal brand all-purpose flour in 110 ml DI water (3)</td>
</tr>
<tr>
<td><strong>Texture (Chicken)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Springiness</td>
<td>Amount/ degree the sample returns to its original shape after partial compression- first bite</td>
<td>Sour Patch Watermelons (4)</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>Distance you can bite into the sample before it breaks, cracks, crumbles- first bite</td>
<td>Sour Patch Watermelons (4)</td>
</tr>
<tr>
<td>Hardness</td>
<td>Force to compress the sample with the molars during first two bites</td>
<td>Krave Basil Citrus Turkey Jerky (4)</td>
</tr>
<tr>
<td>Moisture release</td>
<td>Amount of moisture coming from the sample during the first five chews</td>
<td>John Soules Foods Fully Cooked Chicken Breast Strips with Rib Meat Grilled (4)</td>
</tr>
<tr>
<td>Chewiness</td>
<td>Amount of work to chew the sample to the point of swallow</td>
<td>Sour Patch Watermelons (4)</td>
</tr>
<tr>
<td><strong>Mouthfeel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat</td>
<td>Chemical burning, sensation in the mouth and throat</td>
<td>Red pepper at 0.15% (w/v) in water, filter after 30 minutes (1)</td>
</tr>
<tr>
<td>Fatty mouthcoating</td>
<td>Fatty film that covers or coats the mouth and throat, likely apparent in the aftertaste/ feel</td>
<td>Room temperature heavy whipping cream (1)</td>
</tr>
<tr>
<td>Creamy</td>
<td>A soft, elastic, velvety and full feeling in the mouth</td>
<td>Room temperature whipping cream (5)</td>
</tr>
</tbody>
</table>

¹All standards set at an intensity of 10 along a 15-cm line scale as defined by the trained panelists (n=11).
²Numbers in parentheses correspond to: 1- (Civille & Lyon, 1996); 2- (Adhikari et al., 2011); 3-(Jones, 2015); 4- (Hong Zhuang et al., 2007); 5- (Weenen et al., 2003).
### Table 3. Chicken pasta meals labeling and formulations with (H) and without (N) the presence of herbs.

<table>
<thead>
<tr>
<th>Label</th>
<th>Pasta</th>
<th>Chicken</th>
<th>Tomato</th>
<th>Onion</th>
<th>Water</th>
<th>UHT Cream</th>
<th>Butter</th>
<th>Starch</th>
<th>Salt</th>
<th>SW Chipotle</th>
<th>Basil</th>
<th>Pepper</th>
<th>Garlic</th>
</tr>
</thead>
<tbody>
<tr>
<td>100H</td>
<td>78</td>
<td>76.5</td>
<td>5.5</td>
<td>2.2</td>
<td>68</td>
<td>62</td>
<td>2.1</td>
<td>1.5</td>
<td><strong>1.08</strong></td>
<td>2.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>75H</td>
<td>78</td>
<td>76.5</td>
<td>5.5</td>
<td>2.2</td>
<td>68</td>
<td>62</td>
<td>2.1</td>
<td>1.5</td>
<td><strong>0.81</strong></td>
<td>2.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>50H</td>
<td>78</td>
<td>76.5</td>
<td>5.5</td>
<td>2.2</td>
<td>68</td>
<td>62</td>
<td>2.1</td>
<td>1.5</td>
<td><strong>0.54</strong></td>
<td>2.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>25H</td>
<td>78</td>
<td>76.5</td>
<td>5.5</td>
<td>2.2</td>
<td>68</td>
<td>62</td>
<td>2.1</td>
<td>1.5</td>
<td><strong>0.27</strong></td>
<td>2.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>100N</td>
<td>78</td>
<td>76.5</td>
<td>5.5</td>
<td>2.2</td>
<td>68</td>
<td>62</td>
<td>2.1</td>
<td>1.5</td>
<td><strong>1.08</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>75N</td>
<td>78</td>
<td>76.5</td>
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<td>62</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
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<td>0</td>
<td>0</td>
</tr>
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<td>25N</td>
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<td>5.5</td>
<td>2.2</td>
<td>68</td>
<td>62</td>
<td>2.1</td>
<td>1.5</td>
<td><strong>0.27</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1. **100H** indicates 100% salt from the original formulation, **75H** indicates 75% of original salt concentration, **50H** indicates 50% of original salt concentration, and **25H** indicates 25% of original salt concentration.
2. **Weights** are per 310.5ml tray.
**Table 4.** Summary of MATS processing parameters. For each batch number 18 of the 35 packages processed had herbs and 17 did not. $F_0$ was determined as described above and displayed are the means with SD. There were no significant differences ($p = 0.59$) as determined by a one-way ANOVA between the $F_0$ values.

<table>
<thead>
<tr>
<th>Date</th>
<th>Run Number</th>
<th>Formulation</th>
<th>Number of packages processed</th>
<th>Move Speed (cm/min)</th>
<th>MW Heat Time (min)</th>
<th>MW Hold Time (min)</th>
<th>$F_0$ (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-Apr-17</td>
<td>1</td>
<td>25% Salt</td>
<td>35</td>
<td>68.6</td>
<td>4.72</td>
<td>4.85</td>
<td>17.90 ± 5.11</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>50% Salt</td>
<td>35</td>
<td>69.9</td>
<td>4.64</td>
<td>4.76</td>
<td>14.65 ± 4.31</td>
</tr>
<tr>
<td>11-Apr-17</td>
<td>3</td>
<td>75% Salt</td>
<td>35</td>
<td>72.4</td>
<td>4.47</td>
<td>4.60</td>
<td>14.83 ± 4.69</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>100% Salt</td>
<td>35</td>
<td>73.7</td>
<td>4.40</td>
<td>4.52</td>
<td>12.20 ± 1.27</td>
</tr>
</tbody>
</table>
Table 5. Degrees of freedom and $F$ -ratios from ANOVA of trained panel evaluations of chicken pasta meals for aroma, taste, and flavor attributes. A * represents a significant difference at $p \leq 0.05$.

<table>
<thead>
<tr>
<th>Source $^1$ d f</th>
<th>Aroma</th>
<th>Taste</th>
<th>Flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spice</td>
<td>Tomato</td>
<td>Onion</td>
</tr>
<tr>
<td>R 1</td>
<td>3.5</td>
<td>8.3*</td>
<td>0.2</td>
</tr>
<tr>
<td>T 5</td>
<td>7.6*</td>
<td>6.3*</td>
<td>21.9*</td>
</tr>
<tr>
<td>P 9</td>
<td>82.6*</td>
<td>190.5*</td>
<td>288.7*</td>
</tr>
<tr>
<td>S 7</td>
<td>659.1*</td>
<td>281.1*</td>
<td>120.8*</td>
</tr>
<tr>
<td>T*S 3 5</td>
<td>0.7</td>
<td>0.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

$^1$R-Replicate, T-Storage time, P-Panelist, S-Sample.
Table 6. Degrees of freedom and $F$-ratios from ANOVA of trained panel evaluations of chicken pasta meals for pasta texture, chicken texture, and mouthfeel attributes. A * represents a significant difference at $p \leq 0.05$.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Pasta-Texture</th>
<th>Chicken-Texture</th>
<th>Mouthfeel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Firm</td>
<td>Chew</td>
<td>Crumble</td>
</tr>
<tr>
<td>R</td>
<td>1</td>
<td>5.6*</td>
<td>4.8*</td>
<td>2.7</td>
</tr>
<tr>
<td>T</td>
<td>5</td>
<td>5.4*</td>
<td>4.8*</td>
<td>5.7*</td>
</tr>
<tr>
<td>P</td>
<td>9</td>
<td>151.8*</td>
<td>250.9*</td>
<td>362.6*</td>
</tr>
<tr>
<td>S</td>
<td>7</td>
<td>3.1*</td>
<td>1.9</td>
<td>0.6</td>
</tr>
<tr>
<td>T*S</td>
<td>35</td>
<td>1.1</td>
<td>1.4</td>
<td>0.7</td>
</tr>
</tbody>
</table>

1R-Replicate, T-Storage time, P-Panelist, S-Sample,  
2Firm-Firmness, Chew-Chewiness, Crumble-Crumbliness, Starch-Starchiness  
3Spring-Springiness, Cohesive-Cohesiveness, Hard-Hardness, Moisture- Moisture release, Chew-Chewiness  
4Fatty- Fatty mouthcoating
Table 7. LS mean values for the samples for aroma, taste, and flavor attributes, collapsed over time, panelist, and replicate (n=120). Different letters in the same column indicate significant differences between samples as analyzed by Tukey’s HSD on a 15-cm unstructured line scale, with results presented on this scale between 0 and 15 (p ≤ 0.05).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Aroma</th>
<th>Taste</th>
<th>Flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spice</td>
<td>Tomato</td>
<td>Onion</td>
</tr>
<tr>
<td>100H</td>
<td>7.19&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.68&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.83&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>75H</td>
<td>7.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.57&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.03&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>50H</td>
<td>7.23&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.73&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.03&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>25H</td>
<td>7.48&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.04&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>100N</td>
<td>1.84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.46&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.39&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>75N</td>
<td>1.74&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.35&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>50N</td>
<td>1.80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.37&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>25N</td>
<td>1.81&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.30&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Table 8. LS mean values for the samples for pasta texture, chicken texture, and mouthfeel attributes, collapsed over time, panelist, and replicate (n=120). Different letters in the same column indicate significant differences between samples as analyzed by Tukey’s HSD on a 15-cm unstructured line scale, with results presented on this scale between 0 and 15 (p ≤ 0.05).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Pasta Texture</th>
<th>Chicken Texture</th>
<th>Mouthfeel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Firm</td>
<td>Chew</td>
<td>Crumble</td>
</tr>
<tr>
<td>100H</td>
<td>4.38a</td>
<td>3.72a</td>
<td>4.30a</td>
</tr>
<tr>
<td>75H</td>
<td>4.25ab</td>
<td>3.54a</td>
<td>4.29a</td>
</tr>
<tr>
<td>50H</td>
<td>3.88b</td>
<td>3.30a</td>
<td>4.16a</td>
</tr>
<tr>
<td>25H</td>
<td>3.93ab</td>
<td>3.39a</td>
<td>4.12a</td>
</tr>
<tr>
<td>100N</td>
<td>4.24ab</td>
<td>3.46a</td>
<td>4.14a</td>
</tr>
<tr>
<td>75N</td>
<td>4.28ab</td>
<td>3.49a</td>
<td>4.16a</td>
</tr>
<tr>
<td>50N</td>
<td>4.14ab</td>
<td>3.46a</td>
<td>4.24a</td>
</tr>
<tr>
<td>25N</td>
<td>3.88b</td>
<td>3.50a</td>
<td>4.21a</td>
</tr>
</tbody>
</table>

1Firm-Firmness, Chew-Chewiness, Crumble-Crumbliness, Starch-Starchiness  
2Spring-Springiness, Cohesive-Cohesiveness, Hard-Hardness, Moisture-Moisture release, Chew-Chewiness  
3Fatty-Fatty mouthcoating
Table 9. LS mean values for samples for each attribute evaluated by the consumer panel (n=165). Different letters in the same column indicate significant differences between samples as analyzed by Tukey’s HSD on a 9-point hedonic scale, with results presented on this scale between 1 and 9 (p ≤ 0.05).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Aroma</th>
<th>Appearance</th>
<th>Salt</th>
<th>Umami</th>
<th>Flavor</th>
<th>Pasta Texture</th>
<th>Chicken Texture</th>
<th>Mouthfeel</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>100H</td>
<td>7.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.73&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.84&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.93&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.48&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>50H</td>
<td>7.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.21&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.35&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.88&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.94&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>100N</td>
<td>5.84&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.94&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.94&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.88&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.80&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>5.61&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>50N</td>
<td>5.99&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.39&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.46&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.08&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.62&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.37&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.76&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Figure 1. PCA of all evaluated attributes of the chicken pasta meals as determined by the trained panel. The storage times (in days), collapsed over sample, panelist, and replicate (n=160), are represented as blue dots. Abbreviations for attributes are as follows: P-Pasta texture attribute, A-aroma attribute, Firm-Firmness, Chew-Chewiness, Crumble-Crumbliness, Starch-Starchiness, Spring-Springiness, Cohesive-Cohesiveness, Hard-Hardness, Moisture- Moisture release, Fatty- Fatty mouthcoating
Figure 2. PCA of significant texture and flavor attributes of the chicken pasta meals as determined by the trained panel. The samples are represented as: 100-100% salt, 75%-is 75% of the 100% salt, 50% is 50% of the 100% salt and 25% is 25% of the 100% salt. H indicates the sample with herbs, while N indicates the absence of herbs in the formulation.
Figure 3. The means of the OISE for the different salt concentrations in the chicken pasta meals, collapsed over storage time and replicate. The OISE corresponds to the differences in perceived saltiness among the meals containing herbs (as perceived by the trained panel) and perceived saltiness of the meals with no additional herbs containing the same amount of salt. The error bars represent the standard error of the mean. An asterisk (*) indicate a significant OISE value at p < 0.05. Data from storage times 0, 7, 14, and 21 days were included. Meals were stored at 17°C.
Figure 4. Attribute acceptance of chicken pasta meals stored at 17°C for 6 months and 1 year as evaluated by the consumer panel (n=372 at 6 months; n=288 at 1 year). Storage times prior to 6 months were excluded to ensure salt equilibration was complete before collecting consumer acceptance data. Different letters for the same attribute indicate significant differences between storage times as analyzed by Tukey’s HSD on a 9-point hedonic scale, with results presented on this scale between 1 and 9 (p ≤ 0.05).
Figure 5. Partial least squares correlation biplot of chicken pasta meals and corresponding consumer liking scores and intensity ratings for attributes evaluated by trained panel. The green dots represent the samples as: 100-100% salt and 50% is 50% of the 100% salt, with H indicating the presence of herbs, and N the absence of additional herbs in the formulation. The blue dots represent consumer acceptance data while the red dots represent the data from the trained panel.
CHAPTER V
THE POTENTIAL FOR MICROWAVE TECHNOLOGY AND THE IDEAL PROFILE METHOD TO AID IN SALT REDUCTION

ABSTRACT
This study was the first to evaluate the influence of the combination strategies of flavor addition and microwave-assisted thermal sterilization (MATS) processing for potential salt reduction implications. In mashed potatoes, a 30% and 50% salt reduction in comparison to a 100% salt sample with 3 flavor variations (no additional flavor, garlic, and pepper) were investigated. The influence of MATS vs retort processing, in comparison to a freshly prepared sample, and flavor addition on mashed potato sensory properties and acceptance was investigated with the ideal profile method (IPM). Electronic tongue analysis for non-volatile compounds and HS-SPME/GC-MS for volatile analysis was completed. IPM revealed the ideal data were consistent at both the panel and consumer level from a sensory and hedonic point of view. Results demonstrated the ideal mashed potato product would remain low in bitterness and be higher in pepper and potato aromas and flavors than the current samples evaluated. The salt level could be reduced by 30% while still maintaining salt, flavor, and overall acceptance, but this was accompanied by a loss in saltiness intensity perception. The saltiness intensity was not different from the freshly prepared samples when processed via MATS but was different when processed by the retort. For analytical measures, the electronic tongue showed a high discrimination index (89% -fresh; 95% -processed) and
correlated highly (>0.8) with many sensory attributes. Volatile analysis found as salt concentration decreased, percentage recovery decreased. The present work contributes to the understanding of product reformulation for the purpose of salt reduction.

**PRACTICAL APPLICATION**

Product developers need strategies to bring salt down to target levels while maintaining consumer acceptance. The combination strategies of flavor addition and MATS processing may allow for a new strategy to assist product developers in reaching salt reduction targets.
INTRODUCTION

The FDA draft guidance on voluntary sodium reduction goals in the next 2 and 10 years emphasizes innovative product reformulation (U.S. Department of Health and Human Services, Food and Drug Administration, & Center for Food Safety and Applied Nutrition, 2016). However, reducing sodium in prepared foods remains a challenge for industry as consumer acceptance of reduced sodium foods requires extensive reformulation and consumer sensory testing (Kennedy, 2017). As food companies seek methods and technologies to aid in successful salt reduction within their products, more knowledge addressing salt reduction impacts on food quality, specifically sensory quality, is needed.

While studies have demonstrated that salt reduction is possible with current strategies in the literature, these strategies come with limitations in terms of consumer acceptability (Busch et al., 2013). New strategies for salt reduction will continue to assist food companies in reaching targets set out by the FDA draft guidance. Microwave-assisted thermal sterilization (MATS) is a novel technology that may allow for successful product reformulation in comparison to its traditional processing counterpart, retort processing. This hypothesis is based on the reduced processing time needed with MATS processing in comparison to retort processing to reach the same lethality values, thus potentially allowing for a higher retention of flavors (Tang, 2015).

In addition to processing, product reformulation shows promise as a sodium reduction strategy. The addition of flavor or aroma to products has proved to be successful in aiding in salt reduction as evidenced by a significant odor-induced
saltiness enhancement (OISE) for the aromas of bacon, sardine, anchovy, peanuts, ham, chicken, roquefort cheese, tuna, and comté cheese in simple water solutions containing a small amount of salt (Lawrence et al., 2009). Additionally, recent work demonstrated the addition of herbs into a chicken pasta meal allowed for a 50% reduction in salt content while maintaining the same saltiness intensity perception and overall consumer acceptance (Barnett, Sablani, Tang, & Ross, submitted manuscript). Pepper, in addition to contributing to the aroma and flavor of a sample, interacts with the perceived saltiness by its burn (Prescott & Stevenson, 1995), making it a potentially exceptional candidate for saltiness enhancement with the addition of flavor. With MATS technology potentially maintaining flavors and the addition of flavor having the potential to enhance perceived saltiness, their combination may result in a synergistic effect.

In order to investigate this, potential a rapid sensory evaluation method, the Ideal Profile Method (IPM), was used (Worch, Lê, Punter, & Pagès, 2013). In addition to asking consumers about their acceptance of a product, IPM also asks consumers to rate products on both their perceived and ideal intensities from a list of attributes. This method has been used to help create optimized products. This study is the first to investigate its use in the complex process of sodium reduction.

The electronic tongue has been utilized in recent research to investigate if relationships between its evaluation and sensory evaluation would be elucidated. Studies in cheese, model aqueous solutions, and tomato soup prove its use in discriminating samples (Barnett et al., 2019; Carmi & Benjamin, 2017). Additionally, strong correlations were observed between the electronic tongue and sensory evaluation.
of model aqueous solutions and tomato soups (Barnett et al., 2019). These findings provide evidence for the use of the electronic tongue as a rapid analytical tool in salt reduction. With additional matrices investigated, more credibility to using the electronic tongue as a tool in salt reduction will be merited.

The first objective of this research was to investigate if the added flavors conferred with garlic or black pepper addition may lead to the product being perceived as saltier at lower salt concentrations than in samples with no additional flavors. Furthermore, these flavors may provide different flavor profiles after undergoing different processing methods. Therefore, another objective was to determine if MATS processing results in a higher retention of flavor compared to retorted products, with the result of evaluating the contrast of saltiness and consumer acceptability.

**MATERIALS AND METHODS**

*Sample Preparation*

Fresh mashed potatoes were prepared in small batches at three salt levels and three flavor varieties (unflavored, garlic (garlic oil, Kalsec, Kalamazoo, Mi., U.S.A.) and pepper (aquaresin black pepper, Kalsec) for a total of nine formulations (Table 1). The amount of flavor added was based on a previous study in mashed potatoes (Laurila et al., 1996). The amount of salt in the 100% sodium sample was based on the amount of sodium (multiplied by 2.5 to convert to salt) reported in mashed potatoes within the USDA National Nutrient Database for Standard Reference (USDA, 2018).

Freshly prepared samples were evaluated by consumers, the electronic tongue, and HS-SPME/GC-MS. From the analysis of the freshly prepared samples, six
formulations (Table 1) were selected to undergo thermal processing. The salt concentrations for processing were selected due to significant differences in perceived saltiness perception at those salt concentrations with the addition of the flavors. In addition to aiding in the selection of samples to undergo processing, freshly prepared mashed potatoes were compared to the processed samples to be able to investigate processing effects.

Mashed potato flakes (Oregon Potato Company, Boardman, Or., U.S.A.) were prepared with a 5.5:1 water: potato ratio (Guan, Cheng, Wang, & Tang, 2004). Potato flakes had a sodium content of 0.01% or 13.6mg/100g as determined by sodium inductively coupled plasma mass spectrometry (ICP/MS), AOAC 984.27. The average moisture content of the mashed potatoes was 80.83% (± 0.14 SEM) in the fresh prepared samples and 82.57% (± 0.04 SEM) in the processed samples as determined by AOAC 984.25, with each sample tested in duplicate.

Fresh samples were prepared the morning of sensory testing by heating water with predetermined salt concentrations (Table 1) to a boil (~15 minutes), removing the water-salt solution from the heat, adding in the respective flavor (Table 1), and stirring in the potato flakes until moistened. The prepared mashed potatoes were transferred into glass jars, lids were placed on each jar, and jars were placed into a water bath to maintain a temperature of 70°C ± 3°C. Twenty-five minutes before each sensory evaluation session, 25 g of each sample was placed into a 4 oz. souffle cups (Dart, Mason, Mi., U.S.A.), labeled with a 3-digit code, covered with a lid, and placed under a
food warmer (Hatco Corporation, Milwaukee, Wi., U.S.A.) at setting 6 to maintain temperature.

For the processed mashed potatoes, potato flakes and water, with the salt and flavor concentration for the sample (Table 1) were mixed with a Hobart A-200 stand mixer with the “B” beater attachment (Hobart, Troy, Oh., U.S.A.). Air was removed from the mashed potatoes using a minipack®-torre (Vacupack, Maple Valley, Wa., U.S.A.). Then mashed potatoes were spread into 310.5ml trays (Printpack, Atlanta, Ga., U.S.A.) to a total of 300 g per tray. The trays were sealed using a MULTIVCT 200 (MULTIVAC, Kansas City, MO) at 200°C for 4s under a vacuum of 65mbar.

Thermal Processing Conditions

Six formulations from fresh preparations underwent thermal processing via the pilot scale microwave assisted thermal sterilization (MATS) system at Washington State University in Pullman, Wa., U.S.A. and the retort at the US Army Soldier RDE Ctr. in Natick, Ma., U.S.A. for a total of 12 samples. The MATS system has four sections, the preheating, microwave heating, holding, and cooling section and has previously been described in depth (Resurreccion et al., 2013) As the dielectric loss factor increases with salt content and the power penetration depth decreases with salt content (Guan et al., 2004), all varying salt concentrations were run in separate MATS runs in order to achieve similar $F_0$ values. For this study $F_0 = 6$ was targeted and determined by preliminary studies in which trays prepared in the same manner were processed to identify a processing schedule for each salt concentration. All meals were preheated for 30 min in 61°C water and cooled for 5 min in 61°C water. Microwave heating and
holding times varied by salt concentration. These varied times resulted in similar $F_o$ values as determined using the formula below with data from the temperature measurements coming from mobile metallic sensors and data logging software (TMI-USA, Inc., Reston, VA) (Luan et al., 2013).

$$F_o = \int_0^t \frac{(T-T_r)}{z} \, dt$$

where $T$ is the measured temperature ($^\circ$C); $T_r$ is the reference temperature (121.1°C); $z$ has a value of 10°C for sterilization; and $t$ is the heating time (min). The resulting $F_o$ values were 12.4 min for the 50% sodium sample and 8.5 min for the 100% sodium sample.

Retort processing with an Allpax 3802 retort (38 R&D Spray Retort; Allpax Products LC, Covington, La., U.S.A.) was completed at the US Army Soldier RDE Ctr. in Natick, Ma., U.S.A. to achieve similar $F_o$ values as those obtained in the MATS system. Processing was completed with the same ingredient formulations and trays as used in MATS processing. The retort was brought to 116°C at 253 kPa and after a total processing time of 1 hour 10 minutes, the trays achieved an average $F_o$ of 11.44 min ± 0.53 min (SD). There were no significant differences ($p = 0.12$) as determined by a one-way ANOVA between the $F_o$ values for retort and MATS processed samples.

**Electronic Tongue Analysis**

The analysis on the electronic tongue was conducted as previously described (Diako et al., 2016). Briefly, a potentiometric electronic tongue (Astree II electronic tongue unit, Alpha MOS, Toulouse, France) equipped with an auto sampler (LS48)
analyzed the mashed potatoes based on their response to sensors for non-volatile compounds (saltiness, sourness, sweetness, umami, metallic, bitterness and spiciness). Prior to analysis the mashed potatoes were brought to a 2:1 DI water to mashed potato ratio, blended with a Hamilton Beach immersion blender (Hamilton Beach, Glen Allen, Va., U.S.A.) for 20 seconds, then water was added to reach a 5:1 ratio, and then the mashed potatoes were filtered through P8 Fisher filter paper (Fisher Scientific, Suwanee, Ga., U.S.A.). Mashed potatoes were run on the electronic tongue within 24 hours of sensory evaluation.

The electronic tongue was prepared for analysis by undergoing conditioning, calibration, diagnostics, and overnight hydration of set #5 sensors in Milli-Q water. Prior to sample analysis a confirmatory diagnostic run was completed. The auto sampler was programmed with the following parameters: delay = 0 s; acquisition time = 120 s; stirring rate = 1, and acquisition period = 1. A six-looped sequence consisting of a 10 s sensor cleaning in 25 ml reagent grade Milli-Q filtered water between samples was used during data acquisition. A reference solution of the mashed potatoes prepared with 70% salt and no additional flavoring (70NF) was used for the reference for fresh mashed potato analyses. The 100% salt and no additional flavoring processed via the MATS system (100NM) was used as the reference for all processed mashed potato analyses.

**HS-SPME/GC-MS Analysis**

Headspace solid-phase microextraction (SPME) analyses were performed using a 50/30μm DVB/CAR/PDMS fiber (Supelco, Bellefonte, Pa., U.S.A.). This fiber was selected based on previous literature that evaluated four fiber types to find the best
adapted one for volatile compounds from potato flakes (Laine, Göbel, du Jardin, Feussner, & Fauconnier, 2006). Additionally, this fiber was determined to have the best extraction efficiency among four fibers for *P. nigrum* L. (Liu, Song, & Hu, 2007), which is classified as black, green, and white pepper depending on the harvest period (Steinhaus & Schieberle, 2005), and this fiber has been found to work successfully with garlic peels (de Assunção Araújo Pereira et al., 2012). Each SPME sampling was conducted in triplicate. All mashed potato samples were run within 48 hours of sensory evaluation. A sample was prepared for analysis by SPME by mixing mashed potatoes (4 g), MilliQ water (4mL), and 4μg of 2-methylpentanal for 1 minute at output 80 with a Tekmar TR-10 homogenizer (Tekmar, Cincinnati, Oh., U.S.A.). 2-methylpentanal was selected as an internal standard as this compound has not been found as a volatile of raw, boiled, or baked potatoes (Dresow & Böhm, 2009). The sample was combined with a small stir bar in a 20mL glass vial, and hermetically sealed with a PTFE-coated silicone cap (Gerstel Inc., Linthicum, Md., U.S.A.). Volatiles were extracted using a CTC Combi PAL autosampler (Zwingen, Switzerland). Samples were agitated at 750 RPM (5s on, 2 s off) and were heated at 35°C for 10 min to come to equilibrium (Laine et al., 2006). Subsequent extraction occurred by exposing the fiber to the sample headspace for 1 h. After extraction, the fiber was immediately thermally desorbed in the GC/MS injection port at 270°C (Laine et al., 2006) with the injection done in splitless mode. The fiber was maintained in the GC injector for 15 min to ensure total desorption and avoid inter-run carryover (Castro & Ross, 2015).
The gas chromatography (GC) analysis was performed using a Hewlett-Packard model 6890 gas chromatograph (Palo Alto, Ca., U.S.A.) fitted with a capillary column Hp-5MS (length 30 m, internal diameter 0.25 mm, film thickness 0.25μm; Agilent Technologies, Santa Clara, Ca., U.S.A.). An Hp-5 column has been used successfully for potato flakes, garlic peels and oils, and pepper (de Assunção Araújo Pereira et al., 2012; Laine et al., 2006; Dziri, Casabianca, Hanchi, & Hosni, 2014; Liu et al., 2007). Helium was used at the carrier gas at a constant flow of 1.8mL/min. The oven temperature program was modeled after previous potato flake work; 35°C for 2 min, then to 150°C at 5°C/min and finally to 260°C at 20°C/min and held for 5 min (Laine et al., 2006).

The mass spectra were obtained using a mass selective detector (Hewlett-Packard model 5975C) (Agilent Technologies, Avondale, Pa., U.S.A.) under electron impact ionization with data acquisition completed over an m/z range of 41-400. The confirmation of identified compounds was performed by comparing the observed mass spectra with those recorded in the National Institute of Standards and Technology (NIST) mass spectra library provided by the Chemstation software (version E.02.02.1430) from Agilent Technologies. The quantification of diallyl trisulfide and limonene was performed by constructing standard curves. A five-point standard curve for diallyl trisulfide (CAS: 2050-87-5, ≥98% HPLC; Sigma-Aldrich, St. Louis, Mo., U.S.A.), from 0.25mg/mL to 2.5mg/mL, and limonene (CAS: 5989-27-5, analytical standard, Sigma-Aldrich), from 0.025mg/mL to 0.25mg/mL were constructed. The unknown concentration of diallyl trisulfide and limonene in the mashed potato samples were then determined from the peak areas of the compounds divided by the slope of the
line from the standard curve. All analyses were performed in triplicate (Villamor, Evans, Mattinson, & Ross, 2013).

Consumer Evaluation by the Ideal Profile Method (IPM)

Consumers (fresh testing: n = 107; processed testing: n = 103) were recruited from the Washington State University community through email to the listserv from Compusense scheduling software. All consumers signed a consent form prior to participation that was considered exempt by the WSU Institutional Review Board for the use of human subjects. The freshly prepared mashed potato panel consisted of 56 females and 51 males with an average age of 37 (range 19-77). The processed mashed potato panel consisted of 69 females and 34 males with an average age of 36 (range 20-82). All evaluations were completed in individual sensory booths under white lights. For fresh preparations, the consumers rated nine samples. For thermally processed preparations, consumers rated twelve samples. In each panel the samples were rated for the perceived and ideal intensities of potato, garlic, and pepper aromas and flavors, as well as for salt, bitter, umami, and sweet tastes. Additionally, consumers were asked about their acceptance of the saltiness, flavor, and overall liking of the samples on a 9-point hedonic scale. Consumers rating the perceived and ideal intensities as well as acceptance of a product is the conventional practice of the ideal profile method (IPM), which has been described previously in depth (Worch & Punter, 2015).

Statistical Analysis

Principal component analysis, computation of discrimination index, and partial least square regression of electronic tongue data to panelists sensory scores were
conducted using the Astree® AlphaSoft software (version 12.44; Alpha MOS) (Diako et al., 2016). The loadings and scores from the PCA obtained from the AlphaSoft software were plotted as a PCA biplot using R Base Graphics (R Core Team, 2017).

Data from HS-SPME/GC-MS were analyzed using a one-way ANOVA, with Fisher LSD mean separation to determine significant differences between samples. Analysis of GC data was performed with XLSTAT version 2018.1 (Long Island, Ny., U.S.A.), with significance defined as $p \leq 0.05$.

Data from sensory evaluation was analyzed with Ideal Profile Analysis (IPA) with the free software package SensoMineR v. 108 with R 2.8. IPA methodology has been described in depth (Worch, Crine, Gruel, & Lê, 2014). Briefly, IPA consists of four steps 1) checking for sensory and hedonic consistency in the data, 2) checking for segmentation of consumers and the single ideal assumption, 3) defining the sensory profile of the ideal product used as a reference, and 4) guide on improvement based on the sensory profile of the ideal reference. After checking for consistency, segmentation, and the single ideal assumption, a one-way ANOVA with Fisher LSD mean separation was performed with XLSTAT to determine differences in sensory properties and acceptance of the samples.

RESULTS AND DISCUSSION

Consumer Evaluation by the Ideal Profile Method (IPM)

Sensory Consistency

Ideal profile analysis (IPA), described in depth elsewhere (Worch et al., 2014), revealed the ideal data for both mashed potato panels were consistent at both the overall
panel level and individual consumer level from a sensory point of view (figures not displayed). To be consistent from a sensory point of view at the panel level, the averaged consumer ideal profiles should be projected close to the tested product that they accepted the most (Worch & Punter, 2015; Worch, Lê, Punter, & Pagès, 2013); this was demonstrated during analysis of the IPM data. The mashed potato panels were also consistent from a sensory point of view at the individual consumer level as correlation coefficients measuring the individual sensory consistency of the ideal products were high in each panel. This finding is consistent with previously published IPM literature in which IPM data on 24 projects reported that consumers can be reliable and consistent in their sensory descriptions provided through IPM (Worch et al., 2013).

**Hedonic Consistency**

IPA revealed the ideal data for both mashed potato panels were consistent at both the overall panel and individual consumer level from a hedonic point of view. The ideal product data are considered hedonically consistent if they correspond to an ideal product that would be more accepted than the tested product. As the medians of the ideal products were higher than for the actual products tested, the ideal data were considered consistent from a hedonic point of view at the panel level. The standardized acceptance potentials associated with the ideal mashed potato of each consumer as a function of $R^2$ of the individual models, explaining the hedonic ratings based on sensory descriptions provided by the same consumer, were used to assess the hedonic consistency at the consumer level. Most of the consumers had standardized acceptance potentials that were positive, and the $R^2$ of the corresponding individual models were
Thus, the majority of consumers were consistent from a hedonic point of view and the information they provided could help improve the mashed potatoes. Previous literature has also demonstrated that consumers can be consistent in the hedonic descriptions they provide (Worch et al., 2013).

IPA demonstrated that the consumers were in consensus in their ideal product and their hedonic judgments (figures not displayed). Multivariate analysis with confidence ellipses was used to determine if there was a single or multiple ideals. As all ellipses overlapped, it can be concluded that the consumers associated the mashed potatoes to one unique ideal in each panel (Worch et al., 2014).

The Ideal Map (IdMap) (Figure 1) showed the ideal area of the sensory space that is shared by the maximum number of consumers which allowed for defining the ideal of the reference to match in optimization. The construction of the IdMap based on ideal profiles obtained from consumers has been described previously elsewhere (Worch, Lê, Punter, & Pagès, 2012). For interpretation, the closer a sample is to the darker orange region, the closer it would be to the ideal. Thus, for the freshly prepared mashed potatoes (Figure 1a), the ideal product of references was located close to 100GF. For the processed mashed potatoes, the ideal product of reference was located close to 100NM and 100PR (Figure 1b).

PCA plots compared the mashed potato samples to the ideal intensities found through the IdMap procedure for each sensory panel, one for freshly prepared mashed potatoes and one for processed potatoes. For the freshly prepared mashed potatoes, PC1 explained 45.26% of the variation while PC2 explained 23.36% of the variation (Figure
PC1 was described by the contrasting relationships of umami taste, pepper and potato aroma and flavors with bitterness. Sample separation was observed with the freshly prepared mashed potatoes; the 100GF sample was rated as highest in sweet and salty tastes and garlic flavors and aromas, while the 50NF sample was rated the lowest in these attributes.

For the processed mashed potatoes, PC1 explained 38.46% of the variation while PC2 explained 29.89% of the variation (Figure 2b). PC1 was described by the contrasting relationships of salt taste, pepper aroma and flavor with bitterness. In general, within the processed samples, a decrease in the intensities of aroma, flavor, and taste attributes was observed as the salt concentration was decreased and no additional flavor was added. From the PCA plots, it can be concluded that the ideal mashed potato product would remain low in bitterness and be higher in pepper and potato aromas and flavors than the samples evaluated by the consumers in the current study.

To guide future research and improvement, the Fishbone method could be applied with the ideal product reference from the IdMap used to determine the sensory attributes to adjust, and the priority assigned to these attributes for adjustment (Worch et al., 2014).

Sensory Evaluation

As each consumer panel was consistent at both the panel and consumer level from a sensory and a hedonic point of view, further investigation of the data was warranted. For additional investigation of the IPM data, ANOVA with Fisher LSD mean separations was performed. ANOVA revealed there were no significant 3-way
interactions and only 2 significant 2-way interactions (Table 2). Salt and flavor 
interacted to influence perceived garlic and pepper flavor intensities. For garlic 
intensity, when garlic or no additional flavor was added to the mashed potatoes, mean 
garlic flavor intensity increased when the salt level increased, but when pepper was 
added, there was no difference in garlic flavor intensity by salt level. For pepper flavor 
intensity, when garlic was added to the mashed potatoes, mean pepper flavor intensity 
increased as the salt level increased, but for the addition of pepper, mean pepper 
intensity increased as the salt concentration decreased. Additionally, when no additional 
flavor was added, there was no difference in pepper flavor intensity by salt level.

As there were limited interaction effects, main effects were further investigated to 
determine the influence of salt level, processing method, and flavor addition on sensory 
ratings and acceptance scores.

When investigating the influence of salt level on sensory ratings and acceptance 
several main effects were revealed (Table 3). Generally, as the salt level decreased, so 
did intensity ratings and acceptance; however, this effect varied by the extent of salt 
reduction. Compared to the 100% salt mashed potato sample, a 50% reduction in salt 
resulted in a decreased acceptance of salt, flavor, as well as overall acceptance. In 
addition, decreased ratings for the intensities of salt, umami, sweet, and garlic flavor 
were noted. Contrastingly, the salt level could be reduced by 30%, to 70% of the original 
salt concentration, while still maintaining salt, flavor, and overall acceptance, but this 
was accompanied by a loss in saltiness intensity perception.
Changes in attribute intensity may not alter preference for a food. Conner & Booth (1992) measured the differences in salt preference using the just tolerable difference. These results showed that the distance from the ideal that is just discriminated in preference ratings was larger than the just noticeable difference (jnd) determined using difference thresholds. This suggests preference may not be as sensitive to changes that may be observed across individual attributes (Conner & Booth, 1992). Similarly, Laurila et al. (1996) found for unflavored and garlic-flavored mashed potatoes, hedonic responses were not different between -8 jnds to +5 jnds. For pepper-flavored mashed potatoes, hedonic responses were not different between -9 jnds to +4 jnds. The sensory intensity and acceptance effects found with a 30% reduction in salt in the present study were consistent with the previous observations that noticeable intensity differences in individual attributes do not necessarily alter the preference for the food.

Previous work in mashed potatoes concurs with salt level reductions observed in the present work as demonstrated by a decrease in acceptance when mashed potatoes were subjected to a 50% salt reduction. In this previous work a reference concentration of 0.6% salt, for comparison the salt concentration of the 100% salt sample in the present work was 0.77%, was investigated to determine how difference threshold values impacted just noticeable differences. Salt concentrations could be reduced to 0.31% salt in pepper flavored mashed potatoes, and to 0.36% salt in unflavored and garlic mashed potatoes before significant differences in hedonic responses were observed (Laurila et al., 1996). Thus, once mashed potatoes reached a 50% sodium reduction, consumer
acceptance was no longer maintained. Similarly, in the present work, with a 30% salt reduction, consumer acceptance of the mashed potatoes was maintained, but with a 50% salt reduction, consumer acceptance was negatively affected. The combination of these two studies suggests salt could be reduced between 30-50% while maintaining consumer acceptance of mashed potatoes.

The influence of processing technology on the sensory properties of the mashed potatoes were elucidated. Processing of the mashed potatoes by either MATS or retort resulted in a decreased pepper aroma and flavor, as well as sweetness compared to freshly prepared samples (Table 4).

It is of interest to note that the saltiness intensity was not different from the freshly prepared samples when processed via MATS, but was different when processed by the retort. This is consistent with the observation that MATS foods taste saltier than their conventionally processed counterparts (J. Tang, 2015). However, it should be noted that mashed potatoes processed using the processing methods (MATS vs. retort) did not significantly differ from one another in their saltiness perception. The pepper flavor was less intense after retort processing than after MATS processing. The retention of flavor within the MATS processed mashed potato samples aligns with previous research that reformulated a reduced salt chicken pasta meal with the addition of herbs and processed by the MATS. In this reformulated meal, odor-induced saltiness enhancement (OISE) was observed at lower salt concentrations, demonstrating that aromas from the herb addition were maintained through the processing of the meal (Barnett, Sablani, Tang, & Ross, submitted manuscript). As demonstrated by the F-table
(Table 2), salt, flavor, and overall acceptance did not vary by processing method. Thus, again even with differences in some attribute intensities, consumer acceptance was maintained.

The addition of flavor to the mashed potatoes had a significant influence on many of the sensory attributes, as well as on consumer acceptance (Table 5). Garlic addition increased salt, flavor, and overall acceptance compared to the mashed potatoes with no additional flavor and pepper additions. As may be expected, the addition of garlic led to an increase in garlic aroma and flavor intensities, and the addition of pepper resulted in an increased intensity of pepper aroma and flavor.

**Electronic Tongue Analysis**

In the freshly prepared mashed potatoes, PC1 explained 47.24% of the variation while PC2 explained 29.76% of the variation (Figure 3). PC1 was described by the contrasting relationships of metallic and sweet sensor loadings with the 50PF sample close to the metallic loading and the 50GF sample close to the sweet sensor loading.

In the processed mashed potato samples, PC1 explained 51.24% of the variation with the contrasting relationship of the salty to the metallic electronic tongue sensor loadings (Figure 4). Processed mashed potato samples containing 100% salt were close to the salty sensor loading and those with a 50% salt reduction had a contrasting relationship to the salty sensor loading and were loaded closer to the metallic and umami sensors.

Fresh and processed mashed potatoes had contrasting results in relation to the electronic tongue sensory loading. For the processed mashed potatoes, the samples
containing 100% salt were closer to the salty response as evaluated by the electronic tongue. While for the fresh mashed potatoes, the samples containing 100% salt were contrasting to the salty response as evaluated by the electronic tongue. Previous PCA analysis of tomato soups with different salt mixtures evaluated by the electronic tongue found soups containing higher amounts of sodium loaded closer to the salty sensor of the electronic tongue. However, for the salt solutions in the study, the higher sodium samples were not loaded as close to the salty sensor (Barnett et al., 2019).

The spicy sensor loading of the electronic tongue was close to the 70PF sample, but the 100PR sample was primarily described by its contrasting response to the spicy sensor. Results on the electronic tongue analysis of spicy compounds are still limited, but recent research has demonstrated the ability of the electronic tongue to discriminate among spicy compounds in an effective manner. In this previous study, piperine from black pepper was investigated, and at a high concentration (10mg/L), piperine was close to the spicy sensor loading, but at a medium concentration, piperine contrasted the spicy sensory loading (Paup, Barnett, Diako, & Ross, submitted manuscript). For reference, the present work used 0.01%, or 100mg/L pepper in the formulations, but it should be noted this was diluted 5-fold prior to electronic tongue analysis and was pepper flavoring not pure piperine.

As the sensory evaluation results demonstrated pepper aroma and flavor intensities were lower following retort processing than fresh preparation, some of the spiciness of the pepper may have been lost due to processing. This may explain the contrasting results of the fresh versus the retorted sample in relation to the spicy
sensory loading of the electronic tongue. This finding is in alignment with past spicy electronic tongue research that demonstrated the relationship between the spicy sensor loading and piperine depended on the piperine concentration (Paup et al., submitted manuscript).

The electronic tongue showed a high discrimination index for both the fresh and processed mashed potato samples of 89% and 95%, respectively, indicating its ability to distinguish among the various mashed potato samples. A limitation of the present electronic tongue work was that due to the replacement of the electronic tongue sensors, and different reference samples, comparison cannot be completed between the fresh and processed electronic tongue results.

**Volatile Analysis**

Mashed potatoes samples were also analyzed for the concentration and percentage recovery (%), of volatile compounds associated with garlic (diallyl trisulfide) and pepper (D-limonene) in order to explore the influence of processing on volatile compound recovery. A one-way ANOVA evaluating the influence of sample on the concentration of diallyl trisulfide found the sample was significant (df = 20, F = 24.21, p < 0.0001). Similarly, the sample was significant for the influence of sample on the concentration of D-limonene (df = 20, F = 46.32, p < 0.0001).

As samples significantly influenced the concentrations of volatiles recovered in the sample, mean separation of the samples was performed (Table 6). For the freshly prepared samples with garlic addition, the 100% sodium garlic mashed potato had the highest diallyl trisulfide concentration, 70% in the middle, and the 50% sodium garlic
mashed potato had the lowest diallyl trisulfide concentration. Similarly, as the salt concentration in the mashed potatoes decreased, the percentage recovery of diallyl trisulfide also decreased. All processed mashed potato samples were significantly lower in diallyl trisulfide concentration than the 100% and 70% fresh samples, but they were not significantly different from the 50% fresh sample. Additionally, within salt content, mashed potato samples displayed a lower percentage of diallyl trisulfide recovery when they were processed via MATS or retort than when they were freshly prepared. Although not significant, within the processed samples, the samples processed by the MATS system were higher in diallyl trisulfide concentration, and had a higher percentage recovery than those samples processed by the retort at the same salt concentrations.

For samples with additional pepper, processed mashed potato samples were lower in limonene concentration, and had a lower percentage recovery than the fresh samples at the same salt concentrations. Additionally, retorted samples had a lower percentage recovery of limonene than MATS samples. This aligns with results from sensory analysis that showed retorted samples were lower in pepper flavor intensity than MATS processed samples. It also aligns with previous work that observed black pepper principal aroma compounds, including limonene, were preserved after microwave sanitization treatments (Plessi, Bertelli, & Miglietta, 2002).

Relationships Between Sensory and Analytical Evaluations

Table 7 displays correlation results between the intensity data provided by the consumers in the IPA and the electronic tongue. For freshly prepared mashed potatoes,
correlation coefficients were high (>0.8) for the sensory attributes of salt, umami, and pepper flavor with the overall response of the electronic tongue. For MATS processed mashed potatoes, correlation coefficients were high (>0.8) for salt, sweet, bitter, and umami. For retort processed mashed potatoes, correlation coefficients were high (>0.8) for all evaluated attributes.

These high correlations are in agreement with previous studies that reported high correlations between trained panel evaluations and the response of a potentiometric electronic tongue (Diako et al., 2016; Waldrop & Ross, 2014). The attributes with lower correlation values may be due to the different processing methods in this study. With different processing, mashed potatoes experienced varied sensory differences experienced by the IPM panel. For bitterness in the fresh sample, the lower correlation could be attributed to the panelists not finding bitterness to be sample. Still, the finding that consumers sensory intensity ratings correlated highly to the electronic tongue on many attributes strengthens the argument that consumers can be used reliably to rate intensities of attributes that are not complex (Thierry Worch, Lê, & Punter, 2010). Additionally, the high correlations may allow product developers reformulating for sodium reduction the opportunity to screen samples with the electronic tongue to reduce the burden placed upon subsequent sensory evaluations.

CONCLUSION

The present work contributes to the understanding of product reformulation for the purpose of salt reduction. Product developers need strategies to decrease salt to target levels while maintaining consumer acceptance. The combination strategies of
flavor addition and MATS processing may allow for a new strategy to assist product developers in reaching salt reduction targets.

The present study demonstrated that the salt level of mashed potatoes could be reduced by 30% while still maintaining salt, flavor, and overall acceptance, but it resulted in a decrease in saltiness intensity. Therefore, when reformulating products for a reduced salt content, developers should bear in mind that noticeable intensity differences may not alter the preference for the product. Thus, intensity differences that result in changes in acceptance should be the focus of quality insurance rather than utilizing just noticeable differences for this purpose.

Additionally, the present work demonstrated that the electronic tongue correlated highly with sensory evaluation; this result suggests that it could be useful as a screening tool to reduce the number of samples that would need to undergo sensory evaluation. Another more tool that could be used to screen reduced salt samples for sensory evaluation would be through volatile analysis and HS-SPME/GC-MS. This method demonstrated the percentage recovery of volatiles was dependent on the salt concentration in the mashed potatoes. Lastly, IPM was demonstrated to be useful in this simple matrix of mashed potato, and as a result of data consistency found through IPA, the ideal data can be used in future studies as a guide on improvement.
### Tables

**Table 1.** Mashed potato treatments and formulations (w/w) for fresh and processed mashed potato samples evaluated by the ideal profile method, the electronic tongue, and HS-SPME/GC-MS.

<table>
<thead>
<tr>
<th>Label&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Potato Flakes</th>
<th>Water</th>
<th>Salt</th>
<th>Garlic</th>
<th>Pepper</th>
</tr>
</thead>
<tbody>
<tr>
<td>100NF</td>
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<td>81.81%</td>
<td>0.77%</td>
<td>0</td>
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</tr>
<tr>
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</tr>
<tr>
<td>50NF</td>
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<td>82.00%</td>
<td>0.38%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100GF</td>
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</tr>
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<td>81.95%</td>
<td>0.38%</td>
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<td>0.01%</td>
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<tr>
<td>70PF</td>
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<tr>
<td>50PF</td>
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<td>50NM</td>
<td>17.61%</td>
<td>82.00%</td>
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</tr>
<tr>
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<td>0.38%</td>
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<td>0.38%</td>
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</table>

<sup>a</sup>N-no additional flavor added, G-garlic flavor added, P-pepper flavor added, F-freshly prepared, M- microwave assisted thermal sterilization (MATS) processed, and R- retort processed.
Table 2. *F*-values for the mashed potatoes as determined by the consumers in IPM (fresh mashed potatoes: n = 107; processed mashed potatoes: n = 103) examining the influence of processing - (P), salt (S), flavor (F), and their interactions. Processing was separated into fresh, MATS, and retort processing. A * represents a significant difference at p ≤ 0.05.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>A_Potato Int</th>
<th>A_Garlic Int</th>
<th>A_Pepper Int</th>
<th>Salt Int</th>
<th>Umami Int</th>
<th>Sweet Int</th>
<th>F_Garlic Int</th>
<th>F_Pepper Int</th>
<th>Salt Acc</th>
<th>Flavor Acc</th>
<th>Overall Acc</th>
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</thead>
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<td>3.0*</td>
<td>0.2</td>
<td>188.0*</td>
<td>27.3*</td>
<td>6.6*</td>
<td>15.5*</td>
<td>0.5</td>
<td>51.1*</td>
<td>28.3*</td>
<td>28.3*</td>
</tr>
<tr>
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<td>1.3</td>
<td>4.5*</td>
<td>3.1*</td>
<td>0.7</td>
<td>5.0*</td>
<td>1.0</td>
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<td>F</td>
<td>2</td>
<td>10.5*</td>
<td>811.1*</td>
<td>31.2*</td>
<td>1.3</td>
<td>3.7*</td>
<td>1.5</td>
<td>912.6*</td>
<td>36.1*</td>
<td>4.7*</td>
<td>9.6*</td>
<td>6.7*</td>
</tr>
<tr>
<td>S*P</td>
<td>2</td>
<td>0.5</td>
<td>0.6</td>
<td>2.4</td>
<td>1.9</td>
<td>0.2</td>
<td>1.2</td>
<td>1.5</td>
<td>1.7</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>S*F</td>
<td>4</td>
<td>1.0</td>
<td>1.7</td>
<td>0.7</td>
<td>2.1</td>
<td>0.4</td>
<td>0.7</td>
<td>2.7*</td>
<td>3.3*</td>
<td>1.6</td>
<td>1.5</td>
<td>2.1</td>
</tr>
<tr>
<td>P*F</td>
<td>4</td>
<td>1.0</td>
<td>0.1</td>
<td>0.5</td>
<td>1.7</td>
<td>1.3</td>
<td>0.4</td>
<td>0.3</td>
<td>0.7</td>
<td>1.5</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>S<em>P</em>F</td>
<td>4</td>
<td>0.7</td>
<td>0.5</td>
<td>0.8</td>
<td>0.7</td>
<td>0.7</td>
<td>0.1</td>
<td>0.8</td>
<td>1.0</td>
<td>1.4</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

aA-Aroma, F-Flavor, Int- Intensity ratings were evaluated on an unstructured 10 cm scale anchored by none at 1 and much at 9, and Acc- Acceptance ratings were evaluated on a 9-point scale (1 = Dislike extremely, 9 = Like Extremely).
bOnly attributes that had significant models are displayed. Not displayed: bitter (p = 0.91) and potato flavor (p = 0.07).
**Table 3.** Mean attribute intensities and hedonic scores of the mashed potatoes as determined by the consumers in IPM (fresh mashed potatoes: n = 107; processed mashed potatoes: n = 103) based on salt level of the sample. Different letters in the same column indicate significant differences among treatments as analyzed by Fisher’s LSD (p ≤ 0.05).

<table>
<thead>
<tr>
<th>Salt Level</th>
<th>A_Garlic Int&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Salt Int</th>
<th>Umami Int</th>
<th>Sweet Int</th>
<th>F_Garlic Int</th>
<th>Salt Acc</th>
<th>Flavor Acc</th>
<th>Overall Acc</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3.18a</td>
<td>4.57a</td>
<td>4.29a</td>
<td>2.40a</td>
<td>3.52a</td>
<td>5.87a</td>
<td>5.50a</td>
<td>5.45a</td>
</tr>
<tr>
<td>70</td>
<td>2.98a</td>
<td>3.84b</td>
<td>4.00b</td>
<td>2.46a</td>
<td>3.21b</td>
<td>5.71a</td>
<td>5.32a</td>
<td>5.33a</td>
</tr>
<tr>
<td>50</td>
<td>3.06a</td>
<td>3.02c</td>
<td>3.65c</td>
<td>2.16b</td>
<td>3.09b</td>
<td>5.04b</td>
<td>4.86b</td>
<td>4.81b</td>
</tr>
</tbody>
</table>

<sup>a</sup>A-aroma, F-flavor, Int- Intensity ratings were evaluated on an unstructured 10 cm scale anchored by none at 1 and much at 9, and Acc- Acceptance ratings were evaluated on a 9-point scale (1= Dislike extremely, 9 = Like Extremely).

<sup>b</sup>Only significant attributes for the main effect of salt from **Table 2** are displayed.
Table 4. Mean attribute intensities of the mashed potatoes as determined by the consumers in IPM (fresh mashed potatoes: n = 107; processed mashed potatoes: n = 103) based on processing method of the sample. Different letters in the same column indicate significant differences among treatments as analyzed by Fisher’s LSD (p ≤ 0.05).

<table>
<thead>
<tr>
<th>Processing Method</th>
<th>A_Pepper Int&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Salt Int</th>
<th>Sweet Int</th>
<th>F_Pepper Int</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh (F)</td>
<td>2.38a</td>
<td>3.89a</td>
<td>2.44a</td>
<td>2.39a</td>
</tr>
<tr>
<td>MATS (M)</td>
<td>2.19b</td>
<td>3.80ab</td>
<td>2.20b</td>
<td>2.23b</td>
</tr>
<tr>
<td>Retort (R)</td>
<td>2.10b</td>
<td>3.68b</td>
<td>2.21b</td>
<td>2.05c</td>
</tr>
</tbody>
</table>

<sup>a</sup>A-aroma, F-flavor, and Int- Intensity ratings were evaluated on an unstructured 10 cm scale anchored by none at 1 and much at 9.

<sup>b</sup>Only significant attributes for the main effect of processing from Table 2 are displayed.
Table 5. Mean attribute intensities and hedonic scores of the mashed potatoes as determined by the consumers in IPM (fresh mashed potatoes: n = 107; processed mashed potatoes: n = 103) based on flavor addition to the sample. Different letters in the same column indicate significant differences among treatments as analyzed by Fisher’s LSD (p \leq 0.05).

<table>
<thead>
<tr>
<th>Flavor Additiona</th>
<th>A_Potato Int</th>
<th>A_Garlic Int</th>
<th>A_Pepper Int</th>
<th>Umami Int</th>
<th>F_Garlic Int</th>
<th>F_Pepper Int</th>
<th>Salt Acc</th>
<th>Flavor Acc</th>
<th>Overall Acc</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>4.38a</td>
<td>1.94b</td>
<td>1.87b</td>
<td>3.83b</td>
<td>2.03c</td>
<td>1.84c</td>
<td>5.38b</td>
<td>5.00b</td>
<td>5.00b</td>
</tr>
<tr>
<td>G</td>
<td>3.84c</td>
<td>5.30a</td>
<td>2.40a</td>
<td>4.13a</td>
<td>5.63a</td>
<td>2.37b</td>
<td>5.61a</td>
<td>5.43a</td>
<td>5.36a</td>
</tr>
<tr>
<td>P</td>
<td>4.17b</td>
<td>2.05b</td>
<td>2.48a</td>
<td>3.96ab</td>
<td>2.21b</td>
<td>2.54a</td>
<td>5.36b</td>
<td>5.17b</td>
<td>5.12b</td>
</tr>
</tbody>
</table>

aN-no additional flavor added, G-garlic flavor added, P-pepper flavor added, A-aroma, F-flavor, Int- Intensity ratings were evaluated on an unstructured 10 cm scale anchored by none at 1 and much at 9, and Acc- Acceptance ratings were evaluated on a 9-point scale (1= Dislike extremely, 9 = Like Extremely).

bOnly significant attributes from Table 2 are displayed.
Table 6. Concentrations (mg/mL) of diallyl trisulfide and D-limonene in mashed potato samples as determined by HS-SPME/GC-MS. The mean of triplicate measurements are shown. Different letters in the same column indicate significant differences among treatments as analyzed by Fisher’s LSD (p ≤ 0.05).

<table>
<thead>
<tr>
<th>Sample(^a)</th>
<th>Diallyl Trisulfide Concentration (mg/mL)</th>
<th>Recovery (^b) (%) Diallyl Trisulfide</th>
<th>D-limonene Concentration (mg/L)</th>
<th>Recovery (^c) % D-Limonene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mashed Potatoes with Added Garlic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100GF</td>
<td>1.17(a)</td>
<td>100%</td>
<td>od(c)</td>
<td>-</td>
</tr>
<tr>
<td>100GM</td>
<td>0.10cd</td>
<td>8.61%</td>
<td>od</td>
<td>-</td>
</tr>
<tr>
<td>100GR</td>
<td>0.02cd</td>
<td>1.77%</td>
<td>od</td>
<td>-</td>
</tr>
<tr>
<td>70GF</td>
<td>0.82b</td>
<td>70.15%</td>
<td>od</td>
<td>-</td>
</tr>
<tr>
<td>50GF</td>
<td>0.19c</td>
<td>16.22%</td>
<td>od</td>
<td>-</td>
</tr>
<tr>
<td>50GM</td>
<td>0.05cd</td>
<td>4.26%</td>
<td>od</td>
<td>-</td>
</tr>
<tr>
<td>50GR</td>
<td>0.03cd</td>
<td>2.42%</td>
<td>od</td>
<td>-</td>
</tr>
<tr>
<td>Mashed Potatoes with Added Pepper</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100PF</td>
<td>od</td>
<td>-</td>
<td>2.53(a)</td>
<td>100%</td>
</tr>
<tr>
<td>100PM</td>
<td>od</td>
<td>-</td>
<td>0.42c</td>
<td>16.40%</td>
</tr>
<tr>
<td>100PR</td>
<td>od</td>
<td>-</td>
<td>0.25cd</td>
<td>9.78%</td>
</tr>
<tr>
<td>70PF</td>
<td>od</td>
<td>-</td>
<td>0.74b</td>
<td>29.06%</td>
</tr>
<tr>
<td>50PF</td>
<td>od</td>
<td>-</td>
<td>2.44a</td>
<td>96.35%</td>
</tr>
<tr>
<td>50PM</td>
<td>od</td>
<td>-</td>
<td>0.43bc</td>
<td>16.81%</td>
</tr>
<tr>
<td>50PR</td>
<td>od</td>
<td>-</td>
<td>0.29cd</td>
<td>11.37%</td>
</tr>
</tbody>
</table>

\(^a\)N-no additional flavor added, G-garlic flavor added, P-pepper flavor added, F-freshly prepared, M- microwave assisted thermal sterilization (MATS) processed, and R- retort processed. The following samples are not included in the table due to having undetectable levels of diallyl trisulfide or D-limonene: 100NF, 100NM, 100NR, 70NF, 50NF, 50NM, and 50NR.

\(^b\)Recovery % was based on 100% salt freshly prepared set to 100% recovery, i.e. 100GF was compared to the other samples with added garlic for recovery of diallyl trisulfide and 100PF was compared to the other sample with added pepper for recovery of D-limonene.

\(^c\)od-levels in the sample were below the limit of detection.
Table 7. Correlation ($R^2$) values between the sensory evaluation (IPA panel; fresh mashed potato panel n = 107, processed mashed potato panel= 103) of fresh prepared mashed potatoes (n = 9) and processed mashed potatoes (n=12). Processing was separated into fresh, MATS, and retort processing. Selective sensory attributes, as evaluated by consumers, were correlated to the overall electronic tongue response as analyzed using partial least square regression.

<table>
<thead>
<tr>
<th>Sensory Attribute</th>
<th>$R^2$ Fresh Mashed Potatoes</th>
<th>$R^2$ MATS Mashed Potatoes</th>
<th>$R^2$ Retort Mashed Potatoes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt</td>
<td>0.93</td>
<td>0.97</td>
<td>0.997</td>
</tr>
<tr>
<td>Sweet</td>
<td>0.76</td>
<td>0.89</td>
<td>0.97</td>
</tr>
<tr>
<td>Bitter</td>
<td>0.48</td>
<td>0.88</td>
<td>0.99</td>
</tr>
<tr>
<td>Umami</td>
<td>0.90</td>
<td>0.83</td>
<td>0.99</td>
</tr>
<tr>
<td>Pepper Flavor</td>
<td>0.86</td>
<td>0.32</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Figures

Figure 1. *IdMap* solution defining the ideal of the reference to match in the optimization procedure. Sample names are described in Table 1. The sensory parameters of the ideal product are shown in dark orange. (a) freshly prepared mashed potatoes, (b) processed mashed potatoes.
Figure 2. PCA plots of the ideal product, indicated by the target, obtained from the IdMap and the sensory profiles for the mashed potato samples. Vectors are intensity ratings which were evaluated on an unstructured 10 cm scale anchored by none at 1 and much at 9. Samples are in blue with names described in Table 1. (a) freshly prepared mashed potatoes, (b) processed mashed potatoes.
Figure 3. PCA of the freshly prepared mashed potatoes as evaluated by the electronic tongue. The sensors are indicated by umami, metallic, bitter, sweet, spicy, sour, and salty. The triangles represent triplicate measurements. Samples names are described in Table 1.
Figure 4. PCA of processed mashed potatoes as evaluated by the electronic tongue. The sensors are indicated by umami, metallic, bitter, sweet, spicy, sour, and salty. The triangles represent triplicate measurements. Samples names are described in Table 1.
CHAPTER VI
FROM ABSTRACT TO RECOGNIZABLE: MODELING TENDENCIES OF A BASIC SALT SOLUTION AND A TOMATO SOUP BASED ON AFFECTIVE REACTIONS

ABSTRACT
The objective of this study was to understand the crossmodal interaction between salt taste and shape, specifically, the relationship between consumer affective reactions to a salt solution and a tomato soup. Panelists rated samples for acceptance of basic tastes and overall liking, and molded modeling clay into a shape that best reflected their sensory experience. Data were analyzed using a multinomial logit model and a 2 proportion z-test. Shapes molded were categorized into 6 groups: round, flat, long, pointy, abstract, and recognizable. For solutions, liking of saltiness significantly increased the tendency of molding a recognizable shape over an abstract shape. For tomato soups, higher overall liking increased the tendency of a recognizable shape being molded. Panelists differed in their affective reactions to a salt solution and tomato soup, and the subsequent translation of these reactions into physical shapes, supporting the existence of a crossmodal interaction between taste and shape formation.

PRACTICAL APPLICATION
Information from this research will be useful in understanding the affective responses to salt. The application of modeling clay in food product development can give another avenue by which panelists can express the integration of perceptions, especially in food products that have been reduced in salt. This information may also aid in packaging
development as packages could be shaped into forms that are related to higher acceptance, or into forms commonly associated with the prevailing taste present in a food product so as to convey sensory information to the consumer prior to purchase.
INTRODUCTION

Salt reduction has the potential be one of the most cost-effective ways of reducing the growing burden of non-communicable diseases (Neal et al., 2007). A substantial body of evidence now exists that suggests high salt intake is associated with an array of adverse health conditions (Malta et al., 2018). With approximately 75% of salt intake in European and Northern American diets coming from processed and restaurant foods (Brown et al., 2009), food companies are seeking ways to reduce salt within their products. In order to maintain product quality and retain customer satisfaction, an understanding of salt perception and acceptance is of high importance. Previous work shows that saltiness is accepted at different levels among consumers (Hayes et al., 2010), varies by food type (Hayes et al., 2010), and that salt reduction strategies are matrix dependent (Barnett et al., 2019). Therefore, a thorough understanding of salt perception within the food product undergoing salt reduction is important for salt reduction to be successful.

Objective sensory research reports on salt taste perception and temporality are vast, but the subjective understanding of the salt taste experience is still missing (Obrist et al., 2014). A recent review on the crossmodal correspondences between taste and shape identified associations between different basic tastes and shape features (Velasco, Woods, Petit, et al., 2016). In general, people associate sweet with rounder shapes, while they associate bitter, sour, and to a lesser extent salty, with more angular shapes (Velasco, Woods, Petit, et al., 2016). This roundness/ angularity association with tastes has also been found to apply to typefaces, whereby participants matched rounder types with the word “sweet”, while matching more angular typefaces with the taste words
“bitter,” “salty,” and “sour” (Velasco, Woods, Hyndman, et al., 2015). Additionally,
typeface curvilinearity can influence taste ratings in that round typefaces may enhance
sweetness perception or possibly diminish sourness (Velasco, Hyndman, & Spence,
2018). Taste intensity and acceptance of the taste can be useful predictors in the
roundness/ angularity assigned to the tastant (Velasco, Woods, Liu, & Spence, 2016;

In addition to the roundness/ angularity, other shape features that influence
visual preference, such as symmetry and the number of elements in a shape can
influence shape/ taste matches (Palmer, Schloss, & Sammartino, 2013). The
accumulation of studies showing crossmodal relationships between shapes and basic
tastes suggest that shape features of product design, particularly package design, could
convey taste information prior to product purchase and potentially influence affective

Many scientific fields investigate methods which measure and interpret affective
reactions to a product, with new methods being developed regularly to better
understand affective reactions. For example, within the Human-Computer Interaction
(HCI) field, the importance of affect has become evident and several new methods have
been developed to measure user satisfaction with such systems (Isbister et al., 2006).
One such tool, the Sensory Evaluation Instrument (SEI), a non-verbal tool to elicit
users’ affective reactions, includes 8 objects with different shapes to create a flexible
channel of communication (Isbister et al., 2006). Utilizing SEI may allow consumers an
avenue to better express their subjective taste experiences and for researchers to better
understand salt perception and acceptance within a food product. Indeed, SEI has been
used in previous work with basic taste solutions and was successful in contributing descriptors related to the combined temporal, affective, and embodied experiences of each investigated taste (Obrist et al., 2014). However, in this previous work, when presented with a salty solution, many participants wanted a shape that they could manipulate. The set of 8 objects seemed too permanent when tasting the salty solution and participants wanted something more neutral, or a shape which could be manipulated to describe this taste solution (Obrist et al., 2014). Participants initially testing the SEI also suggested that adding the ability to squeeze or shape the objects with one’s own grip would allow further indication of emotion (Isbister et al., 2006).

Taken together, these previous studies demonstrate the crossmodal correspondence of shape matching to basic tastes. Also, this crossmodal correspondence may allow the manipulation of shapes to be an avenue for consumers to express underlying reactions to products that may be difficult to verbalize. This would then allow participants to have the ability to manipulate a shape to describe their sensory experience with salty taste, and may be of value to better understand the salt-shape crossmodal relationship.

Therefore, the objective of this study was to understand the crossmodal interaction between salt taste and shape formation, specifically the relationship between consumer affective reactions to a basic salt solution and a tomato soup, and the resulting clay figure molded to describe the sensory experience. Tomato soup was selected as an additional matrix for investigation to see if relationships discovered within a simple solution would translate to a more complex matrix. Indeed, tomato soup adds in the complexity of other tastes and flavors with the primary flavor of tomato soup.
being tomato, which has a combined saltiness, sweetness, and sourness profile (Wang et al., 2014).

**MATERIALS AND METHODS**

*Materials*

Food grade sodium chloride (NaCl) (Macron Fine Chemicals, Avantor Performance Materials, Center Valley, Pa., U.S.A.) was used in the solution and tomato soup. No-salt added tomato sauce (Hunt’s, Omaha, Ne., U.S.A.), chopped frozen onions (Safeway brand, Pleasanton, Ca., U.S.A.), cut frozen carrots (Safeway brand), celery (Safeway produce), and spices (McCormick)- oregano, basil, marjoram, thyme, and bay leaf were used for the preparation of tomato soup. Unsalted tops saltine crackers, plastic cups used as cuspidors, and napkins were purchased from Safeway for sensory panels (Pullman, Wa., U.S.A.). For solutions, 2 oz SOLO plastic soufflé containers with lids were used (Dart, Mason, Mi., U.S.A.) and for soups, 6 oz insulated white foam bowls with lids were used (Dart). MilliQ water was obtained through purification (EMD Millipore, Billerica, Ma., U.S.A.).

*Salt Concentration*

The concentration of NaCl for this study was selected based on a 30% reduction from the average concentration of salt added in tomato soup to make the soup “just about right” (JAR) based on saltiness (Wang et al., 2014). This resulted in a soup containing 5.44g/L or 93mM NaCl. This same concentration was also evaluated in a solution to determine potential matrix impacts. This concentration is similar to the supra threshold concentration of 4g/L or 68mM used in previous taste experience studies (Obrist et al., 2014; Velasco, Woods, Deroy, et al., 2015).
**Tomato Soup Preparation**

Tomato soup was prepared as described previously (Barnett et al., 2019). In brief, soup composition and preparation was modeled after a previous study (Wang et al., 2014). On the morning of the sensory evaluation panel, soups were prepared as follows. All vegetables (carrot (49.7g), celery (49.7g), and onion (49.7g)) and herbs (oregano (0.30g), basil (0.60g), marjoram (0.50g), thyme (0.24g), and bay leaf (0.30g)) were added to a stock pot and cooked over medium heat (~105°C) for 5 minutes. The tomato sauce (646.16g) was added, brought to a boil, and cooked for 3 minutes. The water (248.52g) and salt (4.28g) were added and brought to a simmer. The soup simmered for 10 minutes, while maintained at 95°C ± 5°C and being stirred continually. Before blending the soup for a smooth, consistent texture, large pieces of herbs were removed. The prepared soup was placed into a water bath to maintain a temperature of 70°C ± 3°C. Twenty-five minutes before each evaluation session, 25 mL of each soup was placed into a white foam bowl labeled with a 3-digit code, covered with a lid, and placed under a food warmer (Hatco Corporation, Milwaukee, Wi., U.S.A.) to maintain temperature.

**Consumer Evaluation: Salt Solution**

Panelists (n = 97) were recruited from the Washington State University (WSU) community through emails to the listserv created in Compusense Cloud (Guelph, Canada). The study was approved by the WSU Institutional Review Board, and all participants provided written consent prior to participation. Fewer male panelists (n=31) participated in the study compared to females (n=66). The panelists were between the ages of 20 and 71 with an average age of 37. All evaluations were conducted
at the WSU Sensory Evaluation Facility in Pullman, WA under white lights in individual sensory booths.

The panelists rated a 93mM NaCl solution (n=1 sample) along a 9-point hedonic scale (1 = Dislike Extremely; 9 = Like Extremely) for acceptance of saltiness, sweetness, sourness, bitterness, umami, and overall liking. After the hedonic questions, the panelists were asked to comment on what they liked or disliked about the sample. Panelists were then given a 1 oz piece of modeling clay (Crayola LLC, Easton, Pa., U.S.A.) and asked to manipulate it into a shape that they felt accurately described how they felt about the sensations they experienced while tasting the solution. Additionally, they were asked to provide comments describing why they manipulated the shape in the way they did.

**Consumer Evaluation: Tomato Soup**

Panelists (n =105) recruited from the WSU community completed the sensory evaluation of tomato soup. Prior to participation, all panelists signed a written consent form that was approved by the WSU Institutional Review Board for the use of human subjects. The soup panel consisted of 38 males and 67 females between the ages of 20 and 77 with an average age of 36. Again, all evaluations were conducted at the WSU Sensory Evaluation Facility in Pullman, WA under white lights in individual sensory booths.

The panelists rated a 93mM NaCl tomato soup on a 9-point hedonic scale for the acceptance of saltiness, sweetness, sourness, bitterness, umami and overall liking. After the hedonic questions, the panelists were asked to comment on what they liked or disliked about the sample. Panelists then molded a 1 oz piece of modeling clay (Crayola
LLC) into a shape that reflected their sensory experience and provided comments on why they manipulated the shape in the way they did.

**Statistical Analysis**

The multinomial logit model was used to analyze the data (XLSTAT, Addinsoft, New York, Ny., U.S.A.). The abstract shape was used as a reference to evaluate the odds ratios of molding the other 5 shapes ($p < 0.05$). A two-tailed $z$-test on the difference in proportions between the frequency of shapes formed after tasting a salt solution versus a tomato soup was conducted.

**RESULTS AND DISCUSSION**

**Consumer Evaluation: Salt Solution**

The molded shapes ($n=97$) were examined for patterns and consistencies and were subsequently categorized into 6 groups: round ($n=10$), flat ($n=11$), long ($n=8$), pointy ($n=11$), abstract ($n=15$), and recognizable/functional ($n=42$) (**Figure 1**). The number and type of shape categories were determined after examining all the molded clay figures and reviewing the comments made about them. Past research was also considered which suggested broad shape categories that participants may match to when they taste a salty solution versus four other basic taste solutions. SEI, which was previously used to assign a shape to the overall taste experience for the five basic tastes (Obrist et al., 2014), consists of 8 shapes.

While not disclosed to participants, the 8 shapes of SEI were described to aid in the presentation of the current results (**Figure 2**): back row—spiky, pseudopod; next row—anteater, bubbly; next row—stone, doubleball, ball; front—barba papa (Isbister et al., 2006). When visually examined, these 8 SEI shapes fit broadly into 3 of the selected
categories for the current study; round (stone, ball), long (doubleball, barba papa), and pointy (spiky, anteater); the pseudopod and bubbly shapes represented a combination of round and pointy categories.

Many shapes were previously selected in past research by different participants to represent the basic tastes, demonstrating the complexity of the shape-taste relationship. In these past studies, some general trends were observed in the selection of shapes, with some tastes, such as sweet associated with doubleball, barba papa, pseudopod, and bubbly while sour was associated with spiky and anteater shapes. The selection of shapes in these previous studies to describe salty will be described in the proceeding paragraphs in relationship to shapes molded in the present study.

The three additional categories included in the present study, specifically flat, abstract, and recognizable/functional, were added due to the remaining shapes not fitting into the first three categories. In addition, the molded shapes remaining displayed similar aspects.

The inclusion of round, long, and pointy categories incorporates the main themes observed in the SEI objects selected in past research by participants when they tasted a salty solution with a concentration of 4g/L or 68mM (Obrist et al., 2014). For context, in the present study, the concentration of the salt solution was 5.44g/L or 93mM NaCl. In this previous study, Obrist et al. (2014) found salty taste was described by some panelists as having a more smooth and rounded shape. In the present study, comments from panelists who molded a round shape stated that the solution was “smooth, well rounded.” [P23 (Figure 3)] and “It tasted round and full and also felt like it created a round shape in my mouth.” [P85].
The doubleball and barba papa shapes in the SEI set represent a repeating wave or temporal experience (Obrist et al., 2014), and could be considered to be shapes representing the same temporal concept expressed through the long category in the present study. The doubleball and barba papa were also chosen in previous research when tasting the salty solution (Obrist et al., 2014). This temporal aspect was expressed in some of the comments of those participants molding a long shape in the present study. For example, panelists who molded shapes that fit into the long group classification stated, “long and bumpy. Flavor stays in the mouth, and is a bit uncomfortable but not too bad.” [P24], “rolled it into a long log, because of how the taste lingered long in my mouth.” [P42 (Figure 3)], and “The taste started gently. The sensation of saltiness rose to a pleasant level then tapered off.” [P79].

The very pointy shape of the SEI set (spiky) was not one of the main shapes selected to represent salty in previous work, but the bubbly shape with rounded protrusions and described as having a ‘finer granulated and dynamic experience’ was selected (Obrist et al., 2014). In the present study, comments from panelists that molded a pointy shape in this study included, “Salt has always reminded me of little spikes,…it makes me think of prickling sensations.” [P51 (Figure 3)], and “I didn’t really like the sample, so I squished the playdough like I didn’t like it either. The bumpiness too kinda makes me think of salt crystals.” [P18].

Flat was selected as a category in this study, but it was not one of the original SEI shapes. However, participants in past SEI research examining salty taste commented they wanted something more neutral, such as a flat shape to help describe the taste experience (Obrist et al., 2014). Comments from some of the panelists who molded a flat
categorized shape in this study stated, “I made it flat because everything was very drab and flat tasting” [P31], “The sample is plain and no particular character” [P35], and “Flat and without form. No complexity, no ridges or parts stand out.” [P49 (Figure 3)].

After the first four categories of shapes were determined, two large categories of abstract and recognizable/functional were determined based on the remaining molded shapes and corresponding comments. P34 and P74 who molded abstract shapes stated, “The sensation started out smooth and full, like water, but then turned sharp and flat on the back end.” and “... The first flat bottom represents how I felt before I tasted this, plain. Then it twists through each sour/bitterness I tasted and ended with the other flat bottom to show it no longer had an after taste (Figure 3) respectively. Comments from P14 and P83 who molded recognizable/functional shapes were “a sun! while tasting it, I was like ‘wow! that is awesome!’ It was like I was enjoying the sunshine of a Mexico beach.”, and “I manipulated a smiley face because I enjoyed the sample and thought it was a pleasant experience.”, respectively. A recognizable/functional shape (Figure 3) was molded by P72 and described the perception as, “I tried to make a wave. This reminds me of the saltiness of sea water, but in a good way. It’s a pleasant taste of salt that you get in sea air.” After categorizing and examining comments, statistical modeling was completed on the samples to further investigate relationships between molded shapes and affective reactions.

Multinomial logit estimates were determined from the model predicting which clay shape was formed based on acceptance of basic tastes and overall liking by panelists (n=97) after tasting the basic salt solution (Table 1). The formation of more
recognizable shapes was related to greater acceptance across many sensory attributes, including saltiness, bitterness, and overall acceptance, compared to forming an abstract shape. Specifically, as the liking of bitterness and umami increased, the tendency of molding a recognizable shape over an abstract shape significantly increased by 4.02 and 2.61 respectively. These results suggested the more panelists liked these attributes, the more likely they were to form a recognizable shape to describe their perception.

As acceptance increased for saltiness in the salt solution, the panelists’ tendency to form a recognizable shape over an abstract shape increased by 6.42. Rationale for greater acceptance being related to the formation of more recognizable shapes than abstract shapes is consistent with the finding that consumers tend to accept that which they are more familiar with, a concept known as the mere exposure effect (Soga, 2018). For example, familiarity with brands by incidental exposure to the brand name or product package can result in more favorable feeling toward the brand (Janiszewski, 1993). Thus, the idea of the mere exposure effect may be contributing to panelists molding more recognizable shapes when they liked a solution as this represented familiarity, versus forming abstract shapes when they were unsure or did not like the tastes they were experiencing.

Panelists who liked the bitterness of the solution were significantly more likely to form a round, flat, long, or recognizable shape than an abstract shape. Indeed, compared to an abstract shape, liking of the bitterness significantly (p < 0.05) increased the chance of molding a long shape by 7.52, a round shape by 8.33, a flat shape by 6.25, and a recognizable shape by 4.02. Thus, when bitterness liking increased, panelists were more likely to mold anything but a pointy shape, compared to an abstract shape.
A potential explanation for why panelists were more likely to mold anything but a pointy shape when bitterness liking increased may be due to how sharp angled features can be perceived. A previous study reported sharp-angled features were liked less than curved features in presented pairs of emotionally neutral images and meaningless patterns (Bar & Neta, 2006). Further research also demonstrated that as a taste is more disliked, it is more associated with an angular shape versus a round shape (Velasco, Woods, Deroy, et al., 2015). Rationale for this finding comes from the notion that sharp transitions in a contour might convey a sense of threat, and thus potentially may trigger a negative bias (Guthrie & Wiener, 1966). Therefore, a potential hypothesis explaining why the increase in bitterness liking increased all but the pointy shape being formed may be that pointy/ sharp molds were being formed more to convey dislike.

Panelists who liked the umami in the solution more were significantly more likely to form a pointy shape than an abstract shape. Indeed, liking of umami increased the tendency of molding a pointy shape by 4.90 over an abstract shape (p < 0.05). This contrasts a previous finding which reported the less a person likes a taste, the more angular the shape they will choose as its match (Velasco, Woods, Deroy, et al., 2015). However, taste liking only explains part of the roundness/angularity matchings to tastes, and umami is typically matched to more angular shapes than round shapes (Velasco, Woods, Deroy, et al., 2015). Thus, perhaps the panelists in the present study liked and perceived more umami in this sample formed more of a pointy shape to represent the umami taste they were perceiving.

*Consumer Evaluations: Tomato Soup*
For the soup, the molded shapes were categorized into the same 6 groups as for the salt solutions: round (n=7), flat (n=12), long (n=4), pointy (n=19), abstract (n=30), and recognizable/functional (n=33) (Figure 4). Due to the low number of long shapes formed after tasting tomato soups, and only marginal significance of the same multinomial logit model utilized to analyze solutions (p = 0.11), the long category was combined into the pointy category for further analysis. Thus, compared to the shapes molded when evaluating a simple salt solution, a two proportion z-test showed there was a higher frequency of pointy (p = 0.06) and abstract shapes (p = 0.04), fewer long (p = 0.01) shapes, and a similar number of round (p = 0.50), flat (p = 1.00), and recognizable/functional (p = 0.11) shapes molded when evaluating a tomato soup (Table 2).

The difference in the categories molded when tasting a solution versus soup may be due to matrix effects as additional tastes were contributed by soup ingredients. This was evidenced when reviewing comments from panelists about their rationale of molding a specific shape. A common theme for those molding a pointy shape after tasting tomato soup was the sourness, a taste that should not be distinctly present in a pure salt solution. Comments included “sourness tickling” [P3], “I will make a sharpen star because the sourness was strongly felt.” [P12], “I shaped the play-doh into a ball with three sharp points. I felt it was well rounded with salt, sweet, and sour being the pronounced flavors in this soup.” [P18], “rich but with some sourness spikes” [P50], and “the feeling I get is kind of sharp/pointy, like the sourness is spiking in certain areas of my tongue.” [P84].
This theme of sourness presenting as ‘sharp’ has been seen before as in previous work a sour solution was best characterized by SEI shapes with pointy extrusions for many participants (Obrist et al., 2014). Sour tastes have also been shown to be conveyed by angular shapes, typefaces, and names (Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014).

Comments from panelists molding the other shapes, round, flat, abstract, and recognizable, were also investigated. Comments from panelists molding a round shape after tasting the tomato soup included, “Circle, present sweet without sweetness.” [P7], “I formed a round shape because I felt a round fullness in my mouth when tasting the soup. It had a good balance of flavors.” [P25], and “I made a round shape to represent the well-rounded taste and feeling of the sample.” [P39]. All of these comments incorporate aspects of round found with previous crossmodal research; round being associated with sweet (Velasco et al., 2014; Velasco, Woods, Deroy, et al., 2015) and round being associated with liking (Velasco, Woods, Liu, et al., 2016).

Next, the flat category for soups was determined through visual and comment examination. Comments from panelists molding a flat shape after tasting the tomato soup were, “I left it medium-thick and mainly flat, but not totally.” [P40], “It tasted thin, not very robust. It didn't give my mouth a full feeling.” [P96], and “I made the clay into a flat blob, because the sample felt like it fell flat of what it could be. It was also a very one dimensional flavor so I tried to make it very thin.” [P98].

To finish out categorizing the molds after tasting tomato soup, the remaining molds were examined, and comments read, to place the molds into either the abstract or recognizable/ function categories. P27, P36, and P58 who molded abstract shapes.
stated, “I think the tangy sensation inspired the shape”, “The flavor was round and full initially, but tapered into a thin, watery profile.”, and “I made it smooth then added texture by pressing it against my shirt because the soup was smooth with a bit of texture against my tongue” respectively. Comments from P2, P31, and P38 who molded recognizable/ functional shapes were “I manipulated it as a heart. The sample tastes good, ..., peaceful. But I want more sweetness”, “I tried to make it look like waves, because the flavor and rich texture kept coming back as I moved it around my mouth.”, and “I made a flower because I believe soup should be a comforting thing and I also associate flowers with being something comforting and this sample accomplished that”, respectively. These comments again demonstrate the different reactions panelists experienced after tasting, and contribute additional information regarding sample perception that would not have been discovered without the ability for the panelist to describe their experience with the molding clay.

When analyzing the same regression parameters for the molded shapes after tasting the tomato soup (with long shapes combined into the pointy shape category), the model was significant at $\alpha = 0.05$ (LR $\chi^2 = 37.38; p = 0.04$) (Table 3). Forming more recognizable shapes was related to greater overall acceptance compared to forming an abstract shape. Specifically, higher overall liking of the tomato soup significantly increased the likelihood of molding a recognizable shape over an abstract shape by 2.6. These results suggested that the more panelists liked the tomato soup, the more likely they were to form a recognizable shape. As with the solutions, the higher liking being related to more recognizable shapes formed may be attributed to the mere exposure effect described above.
A bar chart with the mean values for each evaluated attribute allows for visual comparison between the acceptance scores for the solutions and soups (Figure 5). Salt, sweet, sour, umami, and overall acceptance attributes were preferred in the tomato soup in comparison to the salt solution. This higher acceptance may suggest that more recognizable shapes were formed when evaluating the soup versus evaluating the solution, however the opposite trend (p = 0.11) was found when a difference in proportions test was conducted (Table 2). This flip in molding tendency for across matrices compared to the within matrix effect may be due to the additional tastes contributed by the tomato soup. As evidenced by comments above, the tomato soup had a prominent sourness, and sourness is related to more angular shapes (Velasco et al., 2014). Therefore, the prominent sourness may be more influential in the shape formed by some panelists after tasting the soup than the acceptance. Previous results show that taste quality, intensity, and participants' liking can all significantly predict the roundness/angularity of the tastants (Velasco, Woods, Liu, et al., 2016).

The implications of these findings may aid product developers looking to reduce salt in their products. By knowing which shapes may convey higher liking of samples overall or the samples’ saltiness, one may be able to shape packages and products in a way that may convey saltiness to the consumer, thus aiding in saltiness enhancement to the product. This enhancement may be able to help overcome some of the loss of saltiness due to reduction. This potential enhancement needs to be tested directly to verify, but this study provides guidance on which shapes may be useful for this potential application; previous research also provides support that expectation set up by shapes can influences people’s product perception (Spence & Ngo, 2012). Shapes that should be
investigated further based on findings from the present study would be recognizable/functional shapes with more curved/rounded features as these shapes were more likely to be molded when acceptance increased.

Another potential application of this research could be the addition of a sensory evaluation tool to the sensory scientist toolbox for examining subjective reactions to products in a nonverbal format, allowing flexibility for the consumer to express their sensory experience. This can provide information about the integration of perceptions from consumers about the product that conventional sensory testing may not.

CONCLUSION

Panelists differed in their affective reactions to a salt solution and a tomato soup and subsequent translation of these reactions into physical shapes, supporting the existence of a crossmodal interaction between taste and shape formation. The knowledge of which shape type is molded may convey which sample was preferred, potentially providing food companies another tool to add to their sensory evaluations. This additional tool would allow consumers to express their sensory experience in a nonverbal format, as not only did the shapes molded allow for the panelist to better describe their subjective experience, they also were related to sample acceptance. The ability of examining molded shapes to determine product preference should be examined on a matrix by matrix basis as different acceptance attributes were significantly impacted after tasting a solution versus a soup. Information gained from this study may also be applicable to product and package design to subconsciously set up specific sensory expectations for the consumer using shape symbolism, but this needs to be investigated further to confirm.
Tables

Table 1. Multinomial logita estimates from the modelb predicting clay shape formed based on acceptance of basic tastes and overall acceptance by panelists (n=97) evaluating a salt solution (93mM NaCl).

<table>
<thead>
<tr>
<th>Categoriesc</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>P value</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Round</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>1.14</td>
<td>0.89</td>
<td>0.20</td>
<td>3.12</td>
</tr>
<tr>
<td>Bitter</td>
<td>2.12</td>
<td>0.80</td>
<td>0.01</td>
<td>8.33</td>
</tr>
<tr>
<td>Umami</td>
<td>0.81</td>
<td>0.59</td>
<td>0.17</td>
<td>2.25</td>
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<td><strong>Flat</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>1.18</td>
<td>0.87</td>
<td>0.18</td>
<td>3.25</td>
</tr>
<tr>
<td>Bitter</td>
<td>1.83</td>
<td>0.80</td>
<td>0.02</td>
<td>6.25</td>
</tr>
<tr>
<td>Umami</td>
<td>0.51</td>
<td>0.56</td>
<td>0.36</td>
<td>1.67</td>
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<tr>
<td><strong>Long</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>-0.57</td>
<td>0.87</td>
<td>0.51</td>
<td>0.56</td>
</tr>
<tr>
<td>Bitter</td>
<td>2.02</td>
<td>0.90</td>
<td>0.02</td>
<td>7.52</td>
</tr>
<tr>
<td>Umami</td>
<td>0.14</td>
<td>0.67</td>
<td>0.83</td>
<td>1.15</td>
</tr>
<tr>
<td><strong>Pointy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>0.94</td>
<td>0.84</td>
<td>0.26</td>
<td>2.56</td>
</tr>
<tr>
<td>Bitter</td>
<td>0.86</td>
<td>0.87</td>
<td>0.32</td>
<td>2.36</td>
</tr>
<tr>
<td>Umami</td>
<td>1.59</td>
<td>0.60</td>
<td>0.01</td>
<td>4.90</td>
</tr>
<tr>
<td><strong>Recognizable</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>1.86</td>
<td>0.72</td>
<td>0.01</td>
<td>6.42</td>
</tr>
<tr>
<td>Bitter</td>
<td>1.39</td>
<td>0.66</td>
<td>0.03</td>
<td>4.02</td>
</tr>
<tr>
<td>Umami</td>
<td>0.96</td>
<td>0.47</td>
<td>0.04</td>
<td>2.61</td>
</tr>
<tr>
<td>Overall</td>
<td>-1.62</td>
<td>0.74</td>
<td>0.03</td>
<td>0.20</td>
</tr>
</tbody>
</table>

aLR χ² = 48.68 (p = 0.018).
bModel parameters included: salt (χ² = 14.99, p = 0.01), sweet (χ² = 7.88, p = 0.16), sour (χ² = 7.44, p = 0.19), bitter (χ² = 10.69, p = 0.06), umami (χ² = 10.31, p = 0.07), and overall acceptance (χ² = 8.59, p = 0.13). Only significant parameters and overall acceptance were presented.
cAll categories are in reference to the abstract category.
Table 2. The number and percentages of molded shapes in each category for salt solutions (n = 97) and tomato soup (n = 105) with p-values from a 2 proportion z-test. Significant difference in proportions was set at p < 0.05.

| Shape       | Salt Solution | | Tomato Soup | | Difference in Proportions |
|-------------|---------------|-----------------|-----------------|-------------------------|
|             | # Molded  | %   | # Molded  | %   | p-value |
| Round       | 10       | 10.31| 7         | 6.67| 0.50    |
| Flat        | 11       | 11.34| 12        | 11.43| 1.00    |
| Long        | 8        | 8.25 | 0         | 0.00 | 0.01a   |
| Pointy      | 11       | 11.34| 23        | 21.90| 0.06a   |
| Abstract    | 15       | 15.46| 30        | 28.57| 0.04    |
| Recognizable| 42       | 43.30| 33        | 31.43| 0.11    |

aThe p-values accompanying the long and pointy differences in proportions are after the 4 shapes that were originally in the long category were placed into the pointy category. Prior to this switch the p-values were 0.31 for the long category and 0.24 for the pointy category.
Table 3. Multinomial logit\(^a\) estimates from the model\(^b\) predicting clay shape formed based on acceptance of basic tastes and overall acceptance by panelists (n=105) evaluating the tomato soup.

<table>
<thead>
<tr>
<th>Categories(^c)</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>P value</th>
<th>Odds Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Round</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>1.34</td>
<td>0.82</td>
<td>0.10</td>
<td>3.82</td>
</tr>
<tr>
<td>Overall</td>
<td>0.84</td>
<td>0.65</td>
<td>0.20</td>
<td>2.31</td>
</tr>
<tr>
<td><strong>Flat</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>0.29</td>
<td>0.39</td>
<td>0.46</td>
<td>1.33</td>
</tr>
<tr>
<td>Overall</td>
<td>-0.04</td>
<td>0.50</td>
<td>0.93</td>
<td>0.96</td>
</tr>
<tr>
<td><strong>Pointy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>0.00</td>
<td>0.31</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>Overall</td>
<td>-0.45</td>
<td>0.39</td>
<td>0.24</td>
<td>0.64</td>
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<tr>
<td><strong>Recognizable</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>-0.30</td>
<td>0.29</td>
<td>0.30</td>
<td>0.74</td>
</tr>
<tr>
<td>Overall</td>
<td>0.95</td>
<td>0.40</td>
<td>0.02</td>
<td>2.59</td>
</tr>
</tbody>
</table>

\(^a\)LR \(\chi^2 = 37.38 \ (p = 0.04)\).
\(^b\)Model parameters included: salt (\(\chi^2 = 6.47, p = 0.17\)), sweet (\(\chi^2 = 6.00, p = 0.20\)), sour (\(\chi^2 = 4.31, p = 0.37\)), bitter (\(\chi^2 = 6.09, p = 0.19\)), umami (\(\chi^2 = 2.17, p = 0.71\)), and overall acceptance (\(\chi^2 = 14.61, p = 0.01\)). Only significant parameters and salt acceptance were presented.
\(^c\)All categories are in reference to the abstract category.
The molded shapes from the consumer evaluation (n=97) of salt (93mM NaCl) solution were categorized into 6 categories: round (n=10), flat (n=11), long (n=8), pointy (n=11), abstract (n=15), and recognizable/functional (n=42).
Figure 2. SEI- Sensual Evaluation Instrument consisting of 8 objects with different shapes; back row—spiky, pseudopod; next row—anteater, bubbly; next row—stone, doubleball, ball; front—barba papa. Used with permission from ACM (Isbister et al., 2006).
Figure 3. Select individual images of molded clay after tasting a 93mM NaCl solution. Captions include the panelist number followed by the category the molded shape was placed.
Figure 4. The molded shapes from the consumer evaluation (n=105) of soups (93mM NaCl) were categorized into 6 categories: round (n=7), flat (n=12), long (n=4), pointy (n=19), abstract (n=30), and recognizable/functional (n=33).
Figure 5. The mean values of the acceptance ratings for each evaluated attribute for the salt solution and soup. The error bars represent the standard error of the mean.
CHAPTER VII
CONCLUSIONS AND FUTURE WORK

Four studies were undertaken to investigate the overall objective of this dissertation research, which was to understand the sensory properties, consumer perception, and chemical changes of ready to eat products that are reformulated for a reduced sodium content. Each study showed that with product reformulation, sodium reduction can be achieved while maintaining saltiness intensity perception and overall consumer acceptance. The strategies investigated for sodium reduction implications were salt mixtures (NaCl, KCl, and CaCl$_2$), odor-induced saltiness enhancement (OISE), a novel thermal processing method (microwave-assisted thermal sterilization- MATS), and a combination of OISE and MATS. The investigated food matrices included a model aqueous solution, a tomato soup, a chicken pasta meal, and mashed potatoes. The level of sodium reduction achieved depended on the strategy used to reformulate the product, as well as on the food matrix under investigation.

In addition to demonstrating the ability of the investigated strategies in sodium reduction, the findings from this research contribute additional tools and knowledge to those looking to reduce sodium within food products. The first study, Chapter III, demonstrated that the electronic tongue could discriminate among various salts and thus could be useful for industry as a screening tool in the development of products with different salt mixtures to reduce the number of samples that would need to be evaluated by sensory panels. Additionally, the first study found mixture design methodology could
be of use to identify a predicted optimum mixture of salts for the product under investigation.

In study two, Chapter IV, the additional herbs added to a prepared meal increased the intensity of certain aromas and flavors and led to increased saltiness perception. Thus, these herbs could be considered in future salt reduction applications as this study demonstrated their congruency with salty taste.

Study three, Chapter V, found that the electronic tongue correlated highly to consumer-rated intensities of sensory attributes, and thus could be of value to complement sensory evaluation in sodium reduction. Accordingly, there may be potential to use the electronic tongue as a screening tool for reduced sodium products, allowing for fewer products that would need to undergo consumer sensory evaluation. Study three also demonstrated the potential for volatile compound analysis to identify reduced sodium products by their decreased volatile compound recovery.

In study four, Chapter VI, a novel method, that explored the crossmodal interaction between salt taste and shape, was investigated to understand consumer affective reactions to a reduced sodium product. Utilizing this novel method in sodium reduced products may allow product developers insights not previously discovered through traditional sensory evaluation methods. Furthermore, the salt-shape crossmodal interaction discovered may aid in packaging development as packages could be shaped into forms that are related to higher acceptance, or into forms commonly associated with the prevailing taste present in a food product so as to convey sensory information to the consumer prior to purchase.
With the new tools and methods developed in these studies, future studies now have more opportunities to advance sodium reduction in ready to eat products. Future studies should investigate the potential of using a combination of salt mixtures, OISE, and MATS processing to determine if utilizing all three strategies may allow for sodium reduction to larger percentages. By using mixture design in combination with the electronic tongue for screening of sodium reduced samples, the number of samples that would need to undergo sensory evaluation for a new food matrix could be reduced. Additionally, during consumer evaluation, allowing consumers to express perceptions by molding modeling clay may allow insights into the product under investigation that would not have been evident without this activity.

As with any set of studies, the current body of research does come with some limitations. Limitations of the current research include the limited salts investigated in the salt mixtures, only one combination of herbs used in OISE studies, and only one novel processing method investigated. Future studies should expand and use other salts or salt substitutes in mixtures, such as other potassium salts, magnesium chloride, organic acids, sea salts, or yeast products. To improve upon the OISE findings in this research, different herb combinations or combinations of herbs with other saltiness enhancers. Saltiness enhancers such as glycine salts, guanylic acid salts, inosinic acid salts, or certain organic acids, should be investigated in complex food matrices. Other combinations may prove to allow for sodium reduction to even larger percentages than presented in the current studies. In addition to MATS processing, other novel processing methods, such as high pressure processing, pulse electric field, food
irradiation, ultrasound, ultraviolet, radio frequency, and ohmic heating, should be investigated for their potentials in aiding in sodium reduction.

Research findings from these studies should be investigated in more food matrices as these studies show that sodium reduction is matrix dependent. While model systems can be of some use for initial screening purposes, until the strategy is applied to the food matrix of interest the complex matrix effects will not be revealed. Specific foods that would benefit from sodium reduction include canned entrees, such as ravioli and chili, frozen dinners, such as burritos and pizzas, pasta mixed dishes, and canned soups.

Overall, these studies advanced the understanding of the sensory properties, consumer perception, and analytical changes of ready to eat products that are reformulated for a reduced sodium content. The central hypothesis of this dissertation was that with product reformulation, sodium reduction can be achieved while maintaining sensory perception and consumer acceptance of the product. Studies completed demonstrated the validity of this central hypothesis. Future studies should continue to expand upon findings from this research by investigating more matrices and combining sodium reduction strategies together.
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