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Sodium Reduction Through Salt Substitute Mixtures, Visual Cues, and Salt Level Statements, and Its Effects on Consumer Perception: A Case of Barbecue Sauce

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SODIUM REDUCTION THROUGH SALT SUBSTITUTE MIXTURES, VISUAL CUES, AND SALT LEVEL STATEMENTS, AND ITS EFFECTS ON CONSUMER PERCEPTION: A CASE OF BARBECUE SAUCE

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Abstract

Cardiovascular diseases are the leading causes of death in the USA and associated with excessive sodium (Na) intake. Thus, reducing the Na intake is vital to alleviate health concerns. One serving of the average Barbecue sauce (BBQs) may contribute around 15%-20% of the daily Na allowance (2,300 mg). No research has evaluated salt substitutes or visual cues on salty taste perception of BBQs, thus it was the aim of this research. Consumer studies followed a Balanced Incomplete Block (BIB) designs. For Study I, BBQs prototypes followed a 3-components (NaCl : KCl : Glycine) mixture design, with 38% - 87% less Na than the average BBQs in the US. In the first part (t=10, k=3, r=9, b=30), 300 consumers rated their saltiness and bitterness liking (9-point), emotion (5-point) and purchase intent (PI) before and after disclosing a sodium claim corresponding to each sample. In the second part (t=8, k=3, r=9, b=24), 240 consumers rated their expected salty and bitter taste intensity evoked solely by the brown color of BBQs, and then their perceived taste intensity (3-point JAR scale). In Study II, BBQs prototypes followed a factorial combination of three brown color levels and two salt levels (with and without). For the consumer test (t=6, k=2, r=5, b=15), 225 consumers rated their expected salty taste evoked by color only, then the perceived taste intensity before and after disclosing the sodium content of the samples, using a JAR scale. In this study, disclosing the sodium content favored the positive emotions of the consumers towards reduced and low sodium BBQs, which in turn enhanced the odds of positive purchase of these products. Also, the brown color of BBQs modulated the expected and actual salty taste perception ($P<0.05$; Cochran-Mantel-Hansel, Stuart Maxwell, and McNemar tests). Our findings implied that food manufacturers may apply visual color cues and use informative sodium reduction statements to develop and promote products with reduced sodium.

Chapter 1. Overall Introduction

1.1. Introduction

Sensory food science stands at the intersection of many research fields and disciplines. A science has grown from technology, driven by the pursuit of understanding human perception and product preference. Sensory food science has evolved from and through psychology, statistics, sociology and physiology (Tuorila & Monteleone, 2009). Moreover, sensory evaluation is the scientific method of analysis used to evoke, measure, analyze, and interpret consumers' responses to food products as perceived through the senses of sight, smell, touch, taste, and hearing. Currently, behavioral as well as health sciences, and neuroscience all contribute to the field of sensory sciences with their perspective and research questions, thus broadening the scope of scientific interest. In the future, sensory and consumer research is predicted to have more emphasis on health and wellness, beyond the use of liking responses and laboratory scenarios (Meiselman, 2013), and to improve research to better represent consumer responses on ecological context, while further incorporating multidisciplinary approach on research (Jaeger *et al.*, 2017). Given its multidisciplinary nature, sensory food science can contribute to the understanding of consumers' responses to changes in food (Jaeger *et al.*, 2017; Murray, Delahunty, & Baxter, 2001).

Current opinions of experts agree that health and wellness are, and will continue to be, critical topics of study and that the skills of sensory and consumer sciences must be applied to understand and promote the health and wellness of consumers (Meiselman, 2013). However, some aspects of current food production and consumption behaviors can be controversial. Salt is one of the most used ingredients in the food industry due to its properties to enhance flavor, limit the growth of foodborne pathogens and spoilage organisms, and other functions related to desired attributes (Dötsch *et al.*, 2009; Doyle & Glass, 2010). Approximately 70% of sodium is consumed outside of the home from meals prepared at restaurants and processed foods (Liem, Miremadi, & Keast, 2011; CDC, 2012). In the United States, the average sodium consumption is 3,400 mg per day, well above its daily recommendation (2,300 mg). Moreover, high sodium intake has shown to be independently associated with increased blood pressure, hence the correlation with cardiovascular disease (Whelton *et al.*, 2018). Despite the clear need to reduce the consumers' sodium consumption, abrupt reduction in saltiness could adversely affect the sensory profile of food products (Dötsch *et al.*, 2009; Liem *et al.*, 2011).

The first US effort to engage industry in lowering the population sodium intake was the National Salt Reduction Initiative (NSRI), initiated in 2009 (Curtis, Clapp, Niederman, Ng, & Angell, 2016). This coalition aimed to decrease the sodium in the US packaged and restaurant foods by 25% by 2014, thus lowering population sodium intake by 20%. Despite significant progress due to industry participation, more than half of 61 food categories failed to meet the target. This highlighted that better strategies are required to reduce sodium consumption further.

One well-known strategy on sodium reduction is through salt substitutes, with potassium chloride (KCl) being one of the most explored alternatives. Sodium chloride (NaCl), the main component in common table salt, has been substituted without perceivable adverse effects on taste between 40% to 50% with KCl in a variety of products (Dötsch *et al.*, 2009; Doyle & Glass, 2010; Kuo & Lee, 2014). At higher proportions, however, KCl exhibits a distinctive bitter off-flavor that has a detrimental effect on the perceived flavor of the products, often described as bitter and metallic (Desmond, 2006). Nevertheless, when used in the appropriate amounts, KCl is an adequate substitute for NaCl in various foods without perceivable sensory drawbacks.

Enhanced saltiness perception, through the multisensory perception of flavor, is another strategy that could help reduce the sodium content in food products. The most consistent results in the area of multisensory perception have been observed on Odor Induced Saltiness Enhancement (OISE) (Chokumnoyporn, *et al.*, 2015; Lawrence *et al.*, 2011). The underlying concept is to use aromas that contribute to the perceived saltiness intensity as an overall result of the sensory stimuli from the food product. This is attributed to cross-modal interactions affecting the consumers' perception of flavor. From a physiological perspective, Stone *et al.* (2013) stated that each sense modality has specific receptors and neural pathways that are unlikely to crossover during the processing of information, although meaningful integration of this information occurs further into more complex structures in the brain. This consideration is critical for understanding the consumers' perception process as an inherently complex stimulus of senses which the brain combines with memories of similar scenarios and integrates the co-occurring information collected from the various senses.

It is well known that sodium is critical for various metabolic processes. However, more than half of the participants that responded to practice behaviors associated to salt intake did not know the daily sodium intake recommendations and only a minimal amount of respondents, less than 10%, were knowledgeable about daily sodium recommendations (Newson *et al.,* 2013). In addition to the high sodium consumption, participants from the United States were the most unaware of the daily salt recommendations according to the study above. From a behavioral perspective, the human predilection for salt is determined by factors related to the consumers' development, habits, and dietary culture (Leshem, 2009a). Thus, it is possible that better understanding from the consumers' perspective, could help drive lower sodium diets. These are aspects that need further research and better understanding.

1.2. Research justification

The Institute of Food Technologists (IFT, 2016) pointed out that there is a need for research and knowledge to help improve public health through the reduction of sodium content in food. This forthcoming research should explore and clarify the mechanisms of saltiness perception and their corresponding signaling pathways in the brain, the consumers' preference for salt and their acceptance to food-based sodium reduction strategies, and how early experiences shape sensory responses, among other topics of interest. These efforts should aim to promote a lower salt preference and ideally reduce sodium intake.

In the United States, high blood pressure alone affects over 75 million adults, which lead to heart disease and stroke, the leading cause of death regardless of gender or age. High sodium consumption is related to high blood pressure (CDC, 2012) thus increasing the risk of heart diseases and strokes. It is estimated that 75% of the sodium is consumed through restaurants and processed foods, unwarily, promoting sodium overconsumption (FDA, 2014; CDC, 2016). Thus, it is important to diminish the consumer's average sodium intake.

The average barbecue sauce in the US contains approximately 15% of the daily sodium recommendations per serving size (USDA, 2012), based on the 2,300 mg of Na per day (USDA, 2017). However, more recent studies showed that the sodium content from condiments and sauces vary from 50-906 mg of sodium per serving size, where the Na range per 100 g was widest for bologna and barbecue sauce with values of 1,212 mg and 986 mg per 100 g, respectively (Ahuja *et al.*, 2015)

There are no publications addressing sodium reduction in barbecue sauces, and no previous efforts have evaluated the effects of salt substitute mixtures, visual cues, and salt level statements on sodium reduction and its effect on taste perception, liking, emotions, or purchase intent of BBQ sauce. Hence the main objective of this research.

1.3. Research objectives

This research work aimed to explore the feasibility of developing acceptable reduced and low-sodium products, barbecue sauce, by using salt substitutes, appropriate health-related information, and visual cues to enhance the consumer's saltiness perception. Taken all together, the work was to improve consumers' perception and acceptance towards reduced sodium products so that the food industry can implement it.

Two different phases were done to address the main objective:

Phase 1- Developing acceptable reduced and low sodium barbecue sauces using mixtures of sodium chloride, potassium chloride, and glycine.

- **Study 1:** Tracking changes in emotional responses and purchase intent caused by sodium reduction claims, and liking of saltiness, bitterness and overall taste of reduced and low sodium barbecue sauces.
    - To evaluate the liking of the perceived saltiness, bitterness and overall taste of reduced- and low-sodium BBQ sauces.
    - To evaluate the effect of the sodium reduction claim on emotional responses for reduced- and low-sodium BBQ sauces.
    - To evaluate the purchase intent of reduced- and low-sodium BBQ sauces as affected by the sodium reduction claim.
- **Study 2:** To evaluate the salty and bitter taste perception of reduced and low sodium barbecue sauces containing sodium chloride, potassium chloride, and glycine.

    - To reduce the sodium content of BBQ sauce with salt mixtures (NaCl, KCl and glycine, Gly).
    - To evaluate the salty and bitter taste perception of reduced- and low-sodium BBQ sauces.
    - To evaluate the congruence between taste expectations evoked by brown color and the actual taste perceptions of saltiness and bitterness of reduced- and low-sodium BBQ sauces.

Phase 2- Evaluating the interaction between brown color cues on salty taste perception of barbecue sauces with and without salt.

- **Study 3:** To evaluate sodium reduction of BBQ sauces through salt substitute mixtures [NaCl, KCl, and Gly], and its effect on salty and bitter taste perception
    - To evaluate the association between brown color and salty taste intensities.
    - To evaluate the effects of brown color on the color-taste interaction within the same salt content.
    - To evaluate the effect of salt claim statements on salty taste perception.

Chapter 2. Literature Review

2.1. A brief history of salt in foods

During the hunter-gathering period, it was estimated that the intake of salt in Paleolithic times was less than 1 g/day probably due to the diet that consisted of equal parts of meat and plants with little amounts of naturally occurring sodium (Ha, 2014). Among the food that humans ingest, most natural foods contain a moderate amount of sodium at most, for example, milk and egg contain 50 and 80 mg/100 g, respectively (Allison & Fouladkhah, 2018). With time, budding civilizations learned to preserve their food, which enabled the beginning of processed foods and was closely associated with the use of salt. The earliest evidence of salt processing dates back to around 6,000 BC, yet only 1,000 years ago salt became one of the world's major trading commodities with the spread of civilization, and the salt intake in the western world increased to an estimate of 5 g/day (Ha, 2014).

With time, people learned to process their food which tends to favor the use of salt. For centuries, sodium chloride (NaCl), commonly known as table salt, has been a prefered ingredient because it improves the sensory properties of many types of foods, enhances the flavor, and serves as a preservative agent (Keast & Breslin, 2003; Liem *et al.*, 2011; Morris, Na, & Johnson, 2008). In our time, sodium is available in an ever-growing variety of processed food, which logically has become the major source of sodium in our diets. Cereals and cereal products, one of the major sources of sodium, contributes to approximately 30-50% of the total sodium intake in the United Kingdom and the United States (Liem *et al.*, 2011). Another contributor to large amounts of sodium are processed meats. Commercial marinades, a major technology in the industry of muscle foods, are a complex solution of water, salt, flavorings, and preservatives to treat meats in order to maximize the consumers' satisfaction (Yusop, O'Sullivan, Kerry, &

Kerry, 2012); however, this also results in an inadvertent contribution of sodium consumption among consumers.

Consumers have accustomed to the salt content of processed foods (Desmond, 2006), a behavioral aspect that disfavors the development of products with reduced salt while promoting sodium consumption. In most countries around the world, the overall salt intake has reached an estimate of 9 to 12 g/day (Ha, 2014). According to recent studies, most consumers in the US are unaware of the daily sodium recommendations (Newson *et al.,* 2013), while the average sodium consumption is 3,400 mg/day, greater than its daily allowance (2,300 mg/day), of which at least 70% comes from restaurant and processed foods (CDC, 2017), and about 90% of which is consumed in the form of common salt (CDC, 2018). The World Health Organization, however, has estimated that over 2.5 million deaths could be prevented each year if the average salt consumption would drop to the recommended level (WHO 2016). This is logical given that high sodium intake has shown to be independently associated with increased blood pressure and thus correlated with cardiovascular disease (Whelton *et al.,* 2018). Despite the clear need to reduce the sodium intake, there are critical factors to consider before removing or replacing the salt in processed foods (Busch, Yong, & Goh, 2013; Desmond, 2006; Kuo & Lee, 2014). Mainly, a radical reduction of salt would not be welcomed by the consumers due to a decrease in the desired sensory properties (Dötsch *et al.,* 2009; Liem *et al.,* 2011), which in turn may result in the failure of these new health-inspired products (Dijksterhuis, 2016).

To summarize this section, it took millions of years for humans to go from 1 to 5 g/day of salt in the absence of processed foods, which is a reasonable explanation for the biological tendency to hoard sodium as an evolutionary response to an environment with limited exposure to this element. In just a few thousand years people’s salt intake reached 9 to 12 g/day, arguably due to the development of technologies but also to a default tendency to seek and prefer the savory taste associated with sodium. It is interesting to consider that the biological craving of sodium engraved in our DNA influenced our behavior throughout the millennia and continued to do so even to a pathological excess (Morris *et al.*, 2008).

2.2. Health concerns associated with sodium intake

A small amount of sodium (Na) is indispensable for the maintenance and proper functioning of several functions in living creatures, including humans. Indeed a lack of sodium or the inability to retain it in the body would be fatal since the distribution of intracellular and extracellular fluids are dependent on sodium (Morris *et al.*, 2008). Interestingly, a recent study described an inverse relationship between depression and dietary sodium (Goldstein & Leshem, 2014). The researchers observed that dietary sodium and depression were inversely related to women only and speculated that men might have been protected by their comparatively higher dietary sodium intake. This study led to the possibility that small beneficial effects of sodium condition consumers' preference of salt and thus promotes behaviors that favor the intake of sodium. It is important to point out that human cases of physiological sodium depletion are very unlikely and often the result of unusual health conditions, for example, renal failure.

The amount of sodium needed to maintain homeostasis, also referred to as the physiological need, is aproximately 500 mg per day (Farquhar, Edwards, Jurkovitz, & Weintraub, 2015), whereas the average sodium consumption is often excessive in several countries around the world. For example, the average sodium intake in the US has been estimated at approximately 8.2-9.4 g NaCl/day, similar to 9.4 g NaCl/ day in the United Kingdom, and higher than 12 g NaCl/day in Asian countries (Liem *et al.*, 2011), thus illustrating that the sodium consumption levels are well above the physiological requirements.

Excessive dietary sodium has been associated with the incidence of gastric cancer, decreased bone mineral density (Liem *et al.*, 2011), high blood pressure, hypertension (Ahuja *et al.*, 2015), cardiovascular disease (CVD) and ischemic heart disease (Ha, 2014), obesity, renal diseases, asthma, and a particularly high risk of stroke (Allison & Fouladkhah, 2018). Strokes alone are the leading cause of death, disability, and dementia among cerebrovascular disease, while high blood pressure was accounted for more CVD deaths among any other preventable factor to cause death (Whelton *et al.*, 2018). The cardiovascular system is particularly vulnerable to excessive sodium in the diet (Ahuja *et al.*, 2015). Unfortunately, approximately 16.7 million individuals from around the world die every year due to cardiovascular diseases (Allison & Fouladkhah, 2018). In contrast, over 2.5 million deaths per year could be avoided if the average salt consumption were reduced to the recommended level of approximately 5 g/day (WHO, 2016). Thus it is a necessity to create consumer willingness to prefer lower sodium products, as one of the main cognitive approaches on sodium reduction (Busch *et al.*, 2013).

To summarize this section, a minimal amount of sodium is essential for the health of people. However, the biological mechanisms of sodium are best adapted to retain this element, and as a result, high sodium diets promote a variety of cardiovascular diseases which may escalate to fatal consequences. This is the current cause of millions of deaths around the world and highlights the strong need to reduce the sodium content in processed foods.

2.3. Sodium reduction

Reducing the sodium intake from its current level will require extensive work and modifications along the food supply in a series of small progress over several years (Farquhar *et al.*, 2015). The Institute of Food Technologists (IFT, 2016) pointed out critical considerations and research gaps in the field of sodium reduction. The sodium reduced products must maintain key attributes such as safety, palatability and shelf life stability. Also, the forthcoming research must aim to better understand the consumers' behavior towards dietary sodium. Taken altogether, future research on sodium reduction will require a comprehensive understanding of the saltiness perception from the consumers' perspective as well as underlying technological implications that will result from lowering the sodium in food products.

While rightfully driven by the adverse health effects of excessive salt intake, the sodium content is not easily removed from food products due to its effects associated with desirable attributes (Busch *et al.*, 2013; Desmond, 2006; Doyle & Glass, 2010; Kuo & Lee, 2014). The major obstacle is that a radical reduction of salt would not be welcomed by the consumers and could result in the failure of the new health-inspired products (Dijksterhuis, 2016). Also, a healthier version of a given food product may be presumed to be less flavorful than its counterpart, thus making the consumers less likely to purchase it (Mai & Hoffmann, 2015). Therefore, the challenge for food scientists and manufacturers is to develop healthier versions of food products that are as palatable and flavorful as conventional food products.

Reducing the content of salt or a sodium-based ingredient in a food product is usually accomplished by increasing or adding a flavorful ingredient to compensate for the effect on taste. Some of these changes may be unintentional, but it is important to consider the potential consequences of reformulating a food product (Ahuja *et al.*, 2015). Some common sodium chloride substitutes are potassium chloride (KCl), calcium chloride, magnesium sulfate (Liem *et al.*, 2011), monosodium glutamate, and calcium diglutamate (Allison & Fouladkhah, 2018). By definition, these substances impart and even enhance the salty taste in food products. However, they also convey undesirable aftertastes such as bitter, metallic and astringent tastes which limits their use in the food industry (Liem *et al.*, 2011). Monosodium glutamate and calcium diglutamate have shown to be an effective alternative to reduce the sodium content of soups as a sole replacer of salt or in combination with each other (Allison & Fouladkhah, 2018); however, they still add sodium to the formulation. KCl is probably the most studied and popular salt substitute despite imparting a lower saltiness equivalence and distinctive bitter off-flavor. Moreover, mixtures of NaCl and KCl have shown to suppress the bitter off-flavor while delivering a synergistic saltiness perception (Breslin, 1996).

Recent studies continue to support the feasibility of reducing the sodium content on food products with promising results. Recent sodium-reduction programs have managed to improve public health while remaining cost-effective (Ahn, Kwon, Kim, & Kim, 2017), which is a critical aspect of the food industry. Furthermore, although drastic sodium changes are hard to accept, the United States population has gradually become more receptive to a diet with less sodium and people are more likely make the transition with little difficulty (Farquhar *et al.*, 2015). Another alternative is to influence the consumers' choice of products by displaying health-related information (Bialkova, Sasse, & Fenko, 2016), alluding to a more cognitive strategy.

To summarize this section, the health concerns associated with sodium overconsumption has been a driver in the development of chemical replacers, substitutes, and even research aiming to better understand how to minimize the increasing incidence of high sodium intake. However, the simplest strategy is to stop consuming foods high in sodium.

2.4. Salty taste perception on sodium reduction

In most cases, salty taste perception begins when a sodium ion reaches an epithelial sodium channel (ENaCs) on the taste receptors, and a subsequent signal travels inwards through the nervous system and sensory neurons until it reaches the gustatory processing regions of the brain (Busch *et al.*, 2013; Dötsch *et al.*, 2009; Doyle & Glass, 2010). The afferent proportional to the concentration of sodium, and the concentration of sodium required to elicit saltiness will vary according to the food product (Liem *et al.*, 2011). However, substances other than salt can impart a salty taste, and the overall taste perception can be modulated through the other senses.

From a culinary perspective, the inclusion of savory ingredients can help compensate for the loss of salty taste among products with reduced sodium. In a frankfurter study, samples with 10% liquid smoke were perceived to be saltier despite having the same amount of sodium than its counterparts, which suggested that the liquid smoke enhanced the salty taste of the product (Morey, Bratcher, Singh, & McKee, 2012). Some other ingredients used to enhance the perceived saltiness on food products are fish sauce (Huynh, Danhi, & Yan, 2016), and soy sauce (Goh *et al.,* 2011; Kremer, Mojet, & Shimojo, 2009). However, these ingredients still contribute to the sodium content of the final food product and impart their particular flavor, which limits its applicability for sodium reduction. Better sodium reduction strategies must seek to enhance the saltiness perception with minimal contribution of sodium or imparting disagreeable off-flavors. Potassium chloride (KCl) is the most extensively studied candidate (Desmond, 2006).

Among current technologies, chemical substitution of salt is perhaps the most explored. These substances are known to impart salty taste similarly as NaCl, table salt, yet salt substitutes do not behave entirely like NaCl and are self-limited due to a combination of factors such as differences in functionality, inherent off-flavors at higher concentrations, and delivering lower saltiness equivalence than sodium chloride. KCl has been studied and reviewed across different food models and categories of processed food products (De Souza *et al.*, 2013; Feltrin, De Souza, Saraiva, Nunes, & Pinheiro, 2015; Gou, Guerrero, Gelabert, & Arnau, 1996; Guàrdia, Guerrero, Gelabert, Gou, & Arnau, 2008; Mueller, Koehler, & Scherf, 2016). At a lesser extent, multisensory perception of taste have also been explored and proven to enhance the saltiness perception with minimal contribution of sodium and minimal alteration of sensory attributes. Salt-congruent aromatic compounds yielded a significantly higher saltiness perception in bullions samples (Batenburg & van der Velden, 2011). Moreover, soy sauce aroma significantly increased the recognition and difference threshold values of salty taste on aqueous solutions with otherwise undetectable salt concentrations (Chokumnoyporn *et al.*, 2015). These examples highlight the technological feasibility of odor-induced saltiness enhancement (OISE).

Regarding interactions between sight and taste, previous studies have shown that some colors can be strongly associated with at least one particular taste, for example, green with sour, and white with salty (Wan *et al.*, 2014). Furthermore, these association between colors and tastes have shown to modulate the identification and the perceived intensity of tastants in aqueous samples (Zampini, Wantling, Phillips, & Spence, 2008). For example, increasing the colorant on a mayonnaise-based dipping sauced resulted in higher saltiness expectations (Sukkwai, Chonpracha, Kijroongrojana, & Prinyawiwatkul, 2017). By means of perceptual constancy, small differences in saltiness may go unnoticed by the consumer as, by the process of integration of information, the overall perception of taste is assimilated into recalled memories evoked from the similarity to conventional products (Dijksterhuis, Boucon, & Le Berre, 2014; Le Berrre, Boucon, Knoop, & Dijksterhuis, 2013).

To summarize this section, table salt, as sodium chloride, has a particular and unique combination of characteristics. It imparts salty taste through specialized sodium ion receptors that convey signals of taste and pleasure to consumers, which makes it difficult to replace and encourages its comsumption. These association to different levels of pleasurable experiences make consumers more likely to consume more sodium despite the serious health efects associated with high dietary sodium. Thus, the effort to preserve the health of consumers is what drives the efforts and curiosity from scientists seeking alternatives to sodium chloride.

2.5. Emotional responses

From a physiological perspective, some changes in mood can be early signs of a lacking diet. However, a specific appetite for ions has seldom been addressed in relation to affective state (Morris *et al.,* 2008). In the publication *Biobehavior of the human love of* salt, Leshem (2009) explains how the human predilection for salt, unlike animals, is determined by behavioral factors related to the individual's development, conditioning, habits, and dietary culture, hence discarding a fact that human sodium consumption is due to a mere biological salt appetite. Current marketing strategies incorporate attractive packages and labels to advertise health or hedonic benefits on food products as a potential source of persuasion that seeks to allure emotional responses from the consumers (Bialkova *et al.*, 2016). From a behavioral perspective, it is possible that better understanding the role of emotions on dietary habits and purchase intent could help promote lower sodium diets.

From a brain science perspective, the reward mechanism can generate "liking" and "wanting" for foods, which in turn influence dietary behaviors. Furthermore, "liking" neuro signals is part of a larger mechanism responsible for regulating arousal, appetite, and pleasure, whereas "wanting" mechanisms are part of opioid pathways that outgrow those of hedonic structures (Berridge, Ho, Richard, & Difeliceantonio, 2010). Thus, the reward mechanisms associated with food can influence consumers' sensation and affection.

Traditionally, the sensory evaluation of food product evaluates basic attributes such visual color, texture, and smell. However, the sensory science community has seen a growth of topics focused on emotion, and online surveys (Meiselman, 2013). Eating is a pleasurable experience, mainly attributed to alluring flavors, and palatability. Taste perception, however, is modulated by a variety of factors including age, genetics and more recently, affective state. Regarding food related emotion responses, there is a rather positive bias named *hedonic asymmetry*, which has been attributed to the overall positive disposition towards foods and to that food products are designed to allure to consumers (Desmet & Schifferstein, 2008).

There are at least three affective behaviors: (1) attitudes which include an evaluative component, (2) emotions which are brief, intense, and focused on a subject of the object, and (3) moods which are enduring and build up over time (King & Meiselman, 2010). In addition, emotions can be conceived on two dimensions, namely positive vs. negative, and pleasure or arousal vs. displeasure. The EsSense Profile® measures short and relatively intense emptional responses about consumer products (King, Meiselman, & Carr, 2010). This innovative approach came to provide a broader perspective on how consumers experience a food product and is now one of the most tools for emotion research (Gutjar *et al.*, 2014; King & Meiselman, 2010).

When encouraging healthier eating behaviors, however, messages should be presented in a positive manner (Mai & Hoffmann, 2015). In addition, health-related campaigns should have an emotional approach, not rational, to strengthen implicit associations to healthier products. For the less-liked sample between two flavors of ice cream, it was observed that the overall hedonic responses increased with the increasing sensation of *satisfaction* associated to games outcomes, as determined by Visual Analog Scales (VAS) with anchors 'extremely unsatisfied' and 'extremely satisfied' (Noel & Dando, 2015). Furthermore, sweet and sour taste varied significantly based on the panelists' ratings of *satisfaction* whereas salty and bitter tastes were not affected. Higher ratings of *satisfaction* resulted in higher sweet taste intensity perception and diminished sour intensity perception, which in turn rendered overall higher hedonic responses for the less-liked sample only. This indicates that the consumers' emotion state could modulate the perceived taste intensity of a product, possibly increasing its hedonic appraisal.

To summarize this section, the inclusion of emotion in the food product and sensory sciences is relatively new which could incorporate into exiting areas that could be aplicable to help reduce the sodium consumption through changed behaviors.

2.6. Health-related statements in sodium reduction

It has been proposed that increasing the awareness of the health risks associated with sodium and a better labeling format may promote the purchase intent of lower salt foods (Ahuja *et al.,* 2015; Grimes, Riddell, & Nowson, 2009). Recent studies showed that consumers' awareness of the daily salt recommendations is generally low based on an international comprehensive online questionnaire on salt intake and associated behaviors (Newson *et al.,* 2013). Furthermore, participants from the United States were the least knowledgeable of the daily salt recommendations, whereas salt reduction is perceived to be healthy and important. This highlights the importance of educating consumers on how to be more aware of their sodium intake in relation to the daily sodium recommendations. Health professionals' advice can help patients reduce their sodium intake by making conscious and informed decisions (Jackson *et al.,* 2016). Marketing strategies already incorporate attractive packages and labels advertising health benefits on food products (Bialkova *et al.,* 2016). When encouraging healthier eating behaviors, however, messages should be presented in a positive manner (Mai & Hoffmann, 2015). In addition, health-related campaigns should have an emotional approach, not rational, to strengthen implicit associations to healthier products.

To summarize this section, high sodium consumption is a reason of concern, and urgent attention is needed to minimize prevent the promotion of a dietary behaviour responsible of millions for deaths every year.

2.7. Barbecue sauce

Barbecue sauce was originated in the United States in the late 1800s, and often added to meat to improve its flavor (Aramouni, Herald, & Abu Ghoush, 2013). Sauces, such as barbecue, are used to improve the appearance, flavor, and texture of food products (Akram, Ahn, Yoon, & Kwon, 2012). According to the National Nutrient Database for Standard Reference, the average serving size of barbecue sauce in the US contains approximately 15% of the daily sodium recommendations (USDA 2012), based on the 2,300 mg of Na per day (USDA, 2017). However, more recent studies showed that the sodium content from condiments and sauces varies from 50-906 mg of sodium per serving size, where the Na range per 100 g was widest for bologna and barbecue sauce with values of 1212 mg and 986 mg, respectively (Ahuja *et al.*, 2015). A food product can be classified as a *High-sodium product* if it contains at least 480mg of Na per serving size, approximately 20% of the daily sodium recommendations (FDA, 2014). There is no official standard of reference for barbecue sauce.

Over half of the food products for *condiments and sauces* exceed the FDA limits for sodium for health foods (480 mg/serving), with sodium content ranging from 50-906 mg of sodium per serving size, or 336 to 5,660 mg per 100 g (Ahuja *et al.*, 2015). Interestingly, the product category of *sauces, dips, gravies, and condiments* had at least a 15% increase in the food products that met the NSRI targets (Curtis *et al.*, 2016), which suggest that sodium reduction strategies have had success among this type of products.

The color of barbecue sauce is partially attributed to the non-enzymatic browning reactions that take place during the processing and storage of barbecue sauce (Chao, Hsu, & Yin, 2009). Ahuja *et al.* (2015) evaluated the sodium content of 125 popular processed and restaurant foods in the U.S. and stated that over half exceeded FDA limits for sodium for healthy foods, and barbecue sauce had one of the widest coefficient of variability. In addition, their extensive use of this kind of sauces may pose health concerns, thus making them important for the food manufacturers and health experts (Akram *et al.*, 2012). The market share of sauces, dressings, and marinades was estimated at over $7.3 billion and predicted to grow 4.5% annually in the USA, and has tripled in Korea (Choi *et al.*, 2015), which reflects its economic relevance and popularity. Therefore, barbecue sauce was proposed as a good candidate for the evaluation of sodium reduction using salt and salt substitute mixtures and visual color cues in this dissertation research.

To summarize this section, barbecue sauce is certainly not an obvious choice among food researchers. However, in consideration of its formulation and some estimates of its impact on sodium intake it could actually become a useful tool for learning.

Chapter 3. Hedonic Responses, and Changes in Emotions and Purchase Intent Caused by Sodium Reduction Claims (SRC) of Reduced and Low Sodium Barbecue Sauces

3.1. Introduction

Health concerns associated with high sodium consumption are rising around the world (Newson *et al.*, 2013; WHO, 2016; Zandstra, Lion, & Newson, 2016). However, sodium intake is a modifiable behavior that can be modulated to prevent hypertension and cardiovascular disease (Jackson *et al.,* 2016). Despite the several efforts to reduce sodium intake, both consumers and food manufacturers must further promote the reduction of sodium consumption (Jackson *et al.*, 2016). Several strategies to reduce the sodium intake have focused on the reduction and substitution of sodium chloride (NaCl), which is frequently used by consumers and manufacturers to impart salty taste in food (Liem *et al.*, 2011). However, up to 50% to 70% of new products fail once released onto the market due to insufficient understanding of the consumers' behavior, particularly when a health-oriented change of the formulation affect the desired sensory attributes of the new health-oriented product (Dijksterhuis, 2016). Further progress on lowering sodium consumption could be achieved through better understanding of consumers' perception and what satisfies them (Jackson *et al.,* 2016; Leshem, 2009a; Suckling & Swift, 2015). Current marketing strategies advertise health benefits on food packages to evoke emotional responses from the consumers (Bialkova *et al.*, 2016).

Salt substitutes, such as potassium chloride, could help reduce the sodium content of food products with minimal effect on the taste. KCl has been extensively studied as a salt substitute across various food products, effectively substituting from 30 to 50% of NaCl without perceivable adverse effects on sensory attributes (Doyle & Glass, 2010; Kloss, Meyer, Graeve, & Vetter, 2015; Kuo & Lee, 2014). However, KCl is inherently limited due to its lesser saltiness equivalence, and a bitter and metallic off-flavors that consumers disapprove (De Souza *et al.*, 2013; Feltrin *et al.*, 2015; Torrico & Prinyawiwatkul, 2015). Glycine (Gly) was also evaluated as a salt substitute replacing up to 20% to 30% of salt in fermented sausages before its adverse off-flavors became perceivable to the consumers (Gelabert, Gou, Guerrero, & Arnau, 2003; Gou *et al.*, 1996). Nevertheless, Gly was shown to reduce KCl bitterness (Gou *et al.*, 1996).

From the consumers' perspective, color can be used as a parameter of the taste perception of a product. Sensory cues can modulate the taste perception and assimilate it into the recalled tasting experiences (Dijksterhuis *et al.*, 2014; Le Berrre *et al.*, 2013). Sukkwai et al. (2017), reported that increasing the colorant on a mayonnaise-based dipping sauce resulted in higher saltiness expectations. However, it remains unclear if the mechanism of interaction relating food color with taste perception is due to perceptual or cognitive processes (Hidaka & Shimoda, 2014). Thus, more research in this area is needed to clarify the mechanisms of associations between colors and tastes.

Barbecue sauce was originated in the United States in the late 1800s, and often added to the meat to improve its flavor (Aramouni *et al.*, 2013). Sauces, such as barbecue, are served to improve the appearance, flavor, and texture of the food products (Akram *et al.*, 2012). The color of barbecue sauce is, in part, due to the non-enzymatic browning reactions that take place during the processing and storage of barbecue sauce (Chao *et al.*, 2009). Commercial barbecue sauce has one of the widest ranges of sodium content up to 986 mg per 100 g (Ahuja *et al.*, 2015), which is relatively high and could be reduced through salt substitutes given its bold flavor profile. Therefore, barbecue sauce was proposed as a good candidate for the evaluation of sodium reduction by means of salt and salt substitute mixtures and sodium content labels.

3.2. Materials and methods

3.2.1. Materials and mixture of salts

All ingredients were obtained from stores and suppliers in the USA: pure tomato puree (Cento Fine Foods, West Deptford, NJ), white vinegar, apple cider vinegar, ground black pepper, and garlic powder (Great Value™, Wal-Mart Stores, Inc., Bentonville, AR), ground cayenne pepper (Zatarin's, New Orleans, LA), powdered mustard (Whole Foods Market Services, Inc., Austin, TX), dark brown sugar (Domino Foods Inc., Yonkers, NJ), unsulphured molasses (B&G Foods Inc., Parsippany, NJ), liquid smoke (The Colgin Companies, Dallas, TX), Saladizer 234 gum (Tic Gums, Belcamp, MD), and water. The salt substitute mixture (2.1% w/w) composed of salt (Great Value™, Wal-Mart Stores, Inc., Bentonville, AR), potassium chloride (FCC grade, Extracts & Ingredients, LTD., Union, NJ, USA) and glycine (Leico Medical, CAS#66-49-5, Glycine USP, 610823, Decatur, AL, USA). These were later mixed according to the proportions detailed in Table 3.1 and Figure 3.1

Table 3.1 Salt substitute mixtures* and microbial results$^{\lambda}$ for reduced and low sodium BBQs.

Treatment ID	%NaCl	%KCl	%Glycine	Na reduction (%)	Classification*	YM	APC
1	60	40	00	38.93	Reduced sodium	<2.7	<3.7
2	50	50	00	48.83	Reduced sodium	<2.7	<3.7
3	45	40	15	53.36	Reduced sodium	<2.7	<3.7
4	40	60	00	58.53	Reduced sodium	<2.7	<3.7
5	40	50	10	58.56	Reduced sodium	<2.7	<3.7
6	30	50	20	65.12	Reduced sodium	<2.7	<3.7
7	30	40	30	65.12	Reduced sodium	<2.7	<3.7
8	25	60	15	73.59	Low sodium	<2.7	<3.7
9	20	50	30	77.85	Low sodium	<2.7	<3.7
10	10	60	30	87.65	Low sodium	<2.7	<3.7

*Classification based on 21CFR101.61. Totaling 21mg of NaCl + KCl + Gly per g of product.
$^{\lambda}$Yeast and molds (YM) and aerobic plate (APC) counts of colony forming units (CFU) expressed as log CFU / g of BBQ sauce.

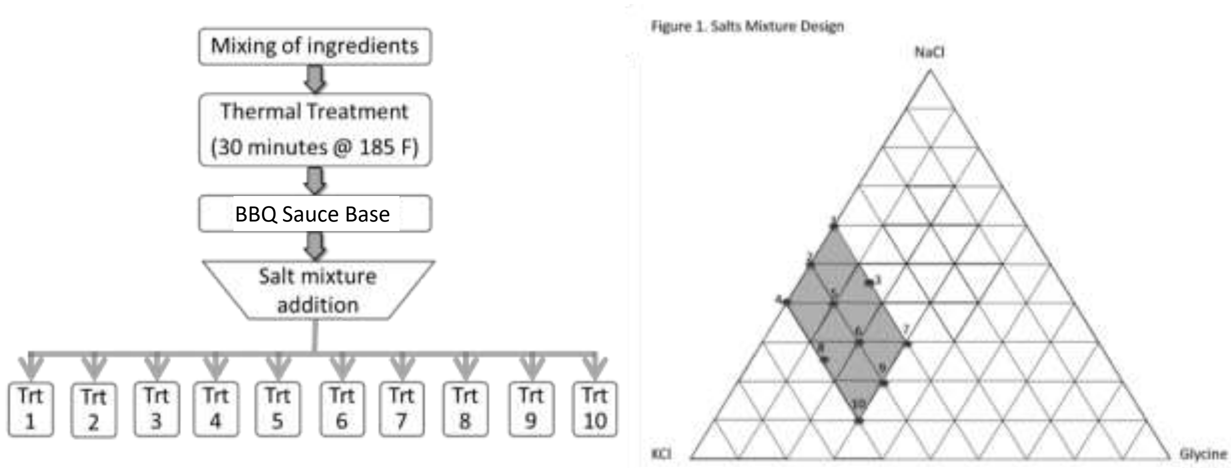

Figure 3.1 Process diagram and constrained region of interest in the mixture design (10 points represent ten treatments in Table 3.1)

3.2.2. Elaboration of BBQ sauce

Ingredients were selected based on its sodium content from a list of over 30 different ingredients used on barbecue sauce recipes found on culinary webpages. The ingredients were arranged in categories (tomato base, sweetener, vinegar, salt, and spices) and ranked according to their frequency of appearance throughout reference formulations. The final amount of salt was estimated based on the National Nutrient Database for Standard Reference from the National Agricultural Library (USDA, 2012).

The base barbecue sauce was prepared as followed. First, water (2% w/w) was incorporated into tomato puree (40% w/w) using a mixer (Globe, SP5-MIXER5QT, Dayton, OH, USA), then simmered and stirred consistently at 180°F for 10 minutes using a kettle (Globe, SP5-MIXER5QT, Dayton, OH, USA). Next, a mixture of dry spices (0.05% ground black pepper, 0.04% ground cayenne pepper, 0.8% mustard flour and 0.5% garlic powder) was incorporated and stalled for 5 min, followed by a mixture of brown sugar (17% w/w), white vinegar (18% w/w), molasses (4.8% w/w) and hydrated gum (0.1% w/w hydrated gum (3% w/w water)). Finally, liquid smoke (3.5% w/w) and apple cider vinegar (9% w/w) were added. The batch was heated for 30 min at 190°F in accordance to 21CFR114 for the thermal process of acidified foods. The base barbecue sauce was poured hot into 1-gallon heavy duty sealable PVC plastic bags (Ziploc, S. C. Johnson & Son, Inc., Louisville, KY, USA) and stored at 5°C.

3.2.3. Experimental design

The experimental design followed a three-component constrained mixture design. The mixtures consisted of NaCl (X_1), KCl (X_2), and Gly (X_3), where the three component proportions summed to 1.0 or 100% (based on 21 mg NaCl+KCl+Gly per gram of product; 2.1% w/w). Ten formulations were evaluated in this research (Figure 3.1). For this study, all formulations met "reduced" or "low-sodium" criteria (no more than 140 mg of sodium per 50 g of sample) (21CFR101.61, CFR, 2017). Using Compusense® *five* software (Compusense Inc., Guelph, Canada), the questionnaire was presented electronically and followed a Balanced Incomplete Block Design (t=10, k=3, r=9, b=30), where each consumer evaluated 3 samples (out of 10 formulations). Samples were presented in 2 oz. plastic cup with three-digit random code, 2×2×2cm cubes of steamed unsalted chicken breast as a carrier for the BBQ sauce, unsalted crackers and tempered water as a palate cleanser. A total of 300 consumers were recruited for this study for a total of 90 replications (observations) per treatment (b*10 = 30*10; = 300 consumers).

3.2.4. Microbiological analysis of barbecue sauces

Total aerobic plate counts (APC) and yeast and molds (YM) were analyzed the day after the preparation of BBQ sauces. BBQ sauces (10 g) were placed into sterile Whirl-pack bags containing 90 ml of phosphate-buffered saline (PBS) and homogenized for 1 min in a stomacher. Serial dilutions in PBS were made, and dilutions were plated onto Petrifilm for APC

(Acumedia®, Neogen, Lansing, MI, USA) and YM (3M®, Saint Paul, MN, USA). Then, APC and YM Petrifilms were incubated for 48 h at 35°C (AOAC®990.12; AOAC International, 2002a) and 24 h at 35°C (AOAC®997.02; AOAC International, 2002b), respectively. After incubation, the colonies were counted and expressed as Log CFU/g of BBQ sauce. For the purpose of this study, microbiological analysis specifically aimed to ensure the safety of consumers. Results (Table 3.1) show that all treatments were safe to consume.

3.2.5. Consumer testing

Emotion terms elicited by food from the EsSense Profile® (King & Meiselman, 2010) were used for the online survey, using QuickSurveys™ program (Toluna QuickSurveys™; Toluna SAS, Levallois-Perret, France). Emotion terms related to the consumption of barbecue sauce were screened using check-all-that-apply (CATA). Emotion terms selected by at least 20% of participants were chosen for the consumer study (King & Meiselman, 2010; Sukkwai *et al.*, 2017). *Adventurous, good, happy, pleased, satisfied,* and *warm* were used as positive emotion terms. *Disgusted, guilty, unsafe,* and *worried* were selected as negative emotions due to a possible relationship with health concerns associated with high sodium intake and the KCl bitterness, given that this study aimed to reduce sodium content in barbecue sauce by mixtures of salt and salt substitutes.

The research protocol for consumer testing was approver (IRB#HE15-9) by the Louisiana State University Agricultural Center Institutional Review Board. Consumer testing was conducted in the Sensory Analysis Laboratory, Animal and Food Sciences building, Louisiana State University, Baton Rouge, LA, USA. All evaluations were performed in partitioned sensory booths with cool natural lighting. The questionnaire was electronically presented to consumers, and data were collected using Compusense® *five* software (Compusense Inc., Guelph, Canada) software, following a Balanced Incomplete Block (BIB) design (t=10, k=3, r=9, b=30). All the participants thoroughly read and electronically signed a consent form to ensure they complied with the screening criteria including (1) being a regular consumer of barbecue sauce, (2) not allergic to any of the ingredients used in the barbecue sauces and (3) to be over 18 years of age. After agreeing to terms outlined in the consent form, consumers were asked for demographic information (age, gender, and race). The ten treatments are shown in Table 3.1 (three per participant, based on the BIB design) were first evaluated on a 9-point hedonic scale (1-Dislike extremely, 5-Neither like nor dislike, 9-Like extremely) for the liking of saltiness, bitterness, and overall taste. Emotion profiles (5-point scale), acceptability, and purchase intent (yes/no scale) were evaluated before and after consumers were given the sodium reduction claim (SRC) accordingly to the classification shown in Table 3.1.

3.2.6. Statistical analyses

All data were analyzed using SAS software 9.4 (SAS Inst., 2015). Percent frequencies were calculated for responses to consumer acceptability and PI questions, and emotion terms selected from the online survey. Analysis of variance (ANOVA) and Tukey's HSD test were performed at $\alpha=0.05$ to analyze the mean differences among treatment responses for the liking of saltiness, bitterness and overall taste, and emotion responses. The McNemar test was performed to analyze significant changes in acceptability and PI 'before' and 'after' receiving the SRC. Logistic regression analysis (LRA) was applied to identify sensory liking attributes and emotion terms that significantly influence PI.

3.3. Results and discussion

3.3.1. Hedonic responses, acceptability, and purchase intent

Hedonic scores were not statistically different among treatments (Table 3.2). Mean values ranged from 5.36-5.92 for bitterness liking, 5.42-6.06 for saltiness liking, and 5.54-6.04 for overall taste liking, based on a 9-point scale. There were no perceivable differences regardless of the proportion of salt, KCl, and Gly.

Table 3.2 Hedonic responses, and effect of SRC on acceptability and purchase intent.

	Treatment	Bitterness Liking ^{NS}	Saltiness Liking ^{NS}	Overall Taste Liking ^{NS}	Acceptability		Purchase Intent	
					Before	After	Before	After
1	Reduced Na	5.74±1.84	6.06±1.95	5.88±1.98	76.67%	77.78%	52.22%	57.78%
2	Reduced Na	5.39±1.63	5.74±1.59	5.66±1.66	76.67%	81.11%	52.22%	55.56%
3	Reduced Na	5.70±1.89	5.79±1.89	5.96±1.91	73.33%	78.89%	60.00%	60.00%
4	Reduced Na	5.63±1.68	5.96±1.72	5.98±1.79	83.33%	87.78%	58.89%	61.11%
5	Reduced Na	5.43±1.77	5.52±1.90	5.56±1.84	77.78%	81.11%	46.67%	53.33%
6	Reduced Na	5.92±1.73	5.94±1.86	6.04±1.72	77.78%	82.22%	**53.33%**	**61.11%**
7	Reduced Na	5.87±1.66	5.94±1.69	5.98±1.80	74.44%	77.78%	**48.89%**	**58.89%**
8	Low Na	5.40±1.59	5.42±1.66	5.61±1.61	72.22%	78.89%	44.44%	50.00%
9	Low Na	5.68±1.67	5.90±1.77	5.99±1.65	81.11%	85.56%	50.00%	47.78%
10	Low Na	5.36±1.61	5.69±1.75	5.54±1.87	71.11%	77.78%	42.22%	44.44%

Mean and standard deviation responses based on 9-point hedonic scale from 90 consumers. ^{NS} No significant differences (P>0.05) between treatments.
Acceptance and Purchase Intent responses before and after disclosing the sodium reduction claim (SRC). Significance of stating the SRC for McNemar Exact test is shown in **bold** (P<0.05) font.

Previous studies on salt and salt substitute mixtures on fermented sausages concluded that the maximum substitution of salt with KCl:Gly mixtures should not exceed 40% -70% to prevent the incidence of sweet and bitter off-flavors, and a decreased saltiness (Gelabert *et al.*, 2003), which is comparatively lower than our results. This incongruence between studies could be attributed to a food-matrix in combination of the mastication and salivation, where KCl/Gly are released from the solid matrix and dissolved into the saliva yielding a supertonic solution, which would not be the case for BBQ sauce since the salt mixtures are homogenously diluted in the liquid matrix (Kuo & Lee, 2014).

Another study comparing only pairs of salt mixtures suggested that the maximum substitution of salt with Gly should be up to 30% on dry-cured loin and fermented sausage (Gou *et al.*, 1996), which is closer to our findings. This suggests that such salt substitute mixtures can impart enough saltiness without evidencing off-flavors, and yielding a taste perception not different from its counterparts with higher NaCl content. Furthermore, the bitter off-flavor became noticeable at 30% and 50% salt substitution with KCl for fermented sausage and dry-cured loins, respectively, and saltiness decreased at 50% salt substitution with KCl for fermented sausage only (Gou *et al.*, 1996), resembling to some extent the conclusions reported by Gelabert et at. (2003). In our study, however, there are no indications of such effects even at 60% salt substitution with KCl. The most possible explanation could be that our study used three-component salt and salt substitute mixtures with the intention to optimize the perceived saltiness while minimizing the incidence of off-flavors. A simpler reason could be that the dry-cured loin and fermented sausage were evaluated by a trained sensory panel whereas the BBQ sauce was evaluated by untrained panelists. A less likely explanation could be that sweet and bitter off-flavors from the salt substitutes could be agreeable or simply go unnoticed among the inherently pungent and complex flavor profile of BBQ sauce.

When salt substitutes such as KCl or Gly impart an inadequate saltiness intensity or evidence their inherent off-flavors on food products, it is very likely to be evidenced by decreased scores from sensory evaluation (Desmond, 2006; Gelabert *et al.*, 2003; Gou *et al.*, 1996; Guàrdia *et al.*, 2008), which was not observed in our results. Thus, our results indicate that up to 90% NaCl substitution with 60% potassium chloride, and 30% glycine is possible in BBQ sauce without adverse effects on saltiness, bitterness, and overall liking responses.

From a cognitive perspective, it is also possible that the consumers' familiarity with BBQ sauce affected their perception. In a study using grilled chicken marinated with various BBQ sauces, results suggested that the US consumers were more familiar with the quintessential flavor of the marinades which was later used to explain their higher hedonic responses in comparison to Korean consumers (Choi *et al.,* 2015). The authors proposed that a sense of *familiarity,* an affective state associated with previous experiences and memories associated with a given product, had provoked the different responses among Korean and US consumers. From a multisensory approach, an ongoing taste perception can be assimilated it into an idealized reminisced intensity evoked from memories with similar types of food product. This effect refers to the perceptual constancy created by expectation and has been observed to both suppress the bitterness perception from chocolate ice cream model (Le Berrre *et al.,* 2013), and to enhance the saltiness perception from sandwich models (Dijksterhuis *et al.*, 2014). These effects imply that small variations in the attributes of food products, such as reduced salt, can go unnoticed given that the perception will become assimilated into the evoked expectations with the help of sensory cues, or by affective associations capable of modulating the consumers' overall perception. These last two alternatives are very interesting and adequate to help understand and interpret the results from this study.

It is worth to mention that the researchers tasted the BBQ sauce samples before carrying out the consumer study to have reasonable certainty that at least one of the treatments were obviously different regarding saltiness or bitterness perception. Nevertheless, that was not the case, and through extended research, it became more likely that unexpected factors governed the consumers' taste perception during this study. If so, this implied that higher cognitive mechanisms triggered by sensory cues and complex affective associations overruled the physiological sensory perception of taste from samples that were strongly believed to perform differently. However, said mechanisms and associations belong to a rather abstract realm of science into psychology. The relative disadvantage is that the interpretations of results rely on what is best described as educated conjectures rather than inferences from hard and objective measurements of solid evidence. This means that the interpretation of this results could be attributed to, say, a strong sense of familiarity from the consumers to the BBQ sauce, which modulated their perceptions into what they expected the sample to taste like due to a simultaneous and unconsciously reminiscing from previous experiences with BBQ sauce. This could arguably be a logical interpretation of the results, particularly if accompanied by an appropriate reference, even in the inexplicable scenario where a panelist evaluated various treatments, yet he walked away convinced that all samples were very similar only because the samples were close enough to his expectations, not based on the physiological perception of taste. However, there is no mean to prove or corroborate the hard validity of this theory in the absence of any hard evidence, except by reproducing the experiment and achieving the same conclusions. This highlights a need for improvement in this study. It is necessary to have a better understanding of the perceived intensity, not liking, of the salty and bitter tastes, along with the expectations and the role of sensory cues that may accompany the flavor perception of taste.

The percent 'yes' responses for acceptability and purchase intent (PI), before and after disclosing the sodium reduction claim (SRC) to the consumers are shown in Table 3.2. The acceptability responses ranged from 71.11%-83.33% and from 78.89%-87.78% before and after disclosing the SRC to the consumers, respectively. Similarly, PI responses ranged from 42.22%-60%, and 44.44%-61.11% before and after disclosing the SRC to the consumers, respectively.

Despite the lack of statistical significance, it is interesting to point out, that treatments 4, 6 and 7 consistently had some of the highest saltiness, bitterness and overall taste liking scores. In addition, treatment 4 had one of the highest acceptability and PI responses, while the PI for treatments 6 and 7 increased ($P<0.05$) from 53.33% to 61.11%, and from 48.89% to 58.89%, respectively, after disclosing SRC. In contrast, treatment 10 consistently presented one of the lowest bitterness and overall taste liking scores, as well as acceptability and PI responses. Thus, hedonic scores are directly correlated with the consumers' acceptability and PI of food products.

Furthermore, disclosing SRC to the consumers had a minimal yet positive net effect on the acceptability and PI responses across all treatments. This is in accordance with findings of Newson *et al.* (2013) in that most consumers consider that reducing sodium is both important and beneficial for their health. In addition, these results reinforced deductions from the previous discussion that pointed out the remarkable sameness between all treatments based on the hedonic responses, and now on the narrow ranges of acceptability or PI responses as well.

To summarize this section, the reduced and low sodium BBQ samples developed in this study generated relatively acceptable scores for saltiness, bitterness, and overall taste liking, and acceptability and PI scores before and after stating the sodium reduction claim. Moreover, a subtle trend suggests that stating the sodium content of the samples favored the acceptability and PI responses particularly at 65% sodium reduction. Thus, sodium reduction of BBs seems viable.

3.3.2. Consumer emotional responses elicited by the consumption of reduced and low-sodium BBQ sauces

Emotion terms were selected according to the EsSence Profile^{TM}. Consumers were asked to respond to each emotion term before and after disclosing the SRC, as shown in Table 3.3. Mostly positive emotion terms were associated with BBQ sauce. According to King & Meiselman (2010), consumers use positive rather than negative terms regarding recalled food experiences or when describing reactions to food products, referred to as positive bias or hedonic asymmetry.

Table 3.3 Emotion responses$^{\lambda}$ before and after disclosing SRC to consumers

Emotion		Treatment^										Standard Error
		1	2	3	4	5	6	7	8	9	10	
Adventurous	Before	2.03	1.78	1.97	2.16	1.71	**2.04**	**1.99**	**1.76**	**1.84**	**1.89**	0.10
	After	2.08	1.86	2.14	2.24	1.83	**2.29**	**2.19**	**1.96**	**2.12**	**2.1**	0.10
Disgusted	Before	1.42	1.4	1.41	1.41	1.5	1.44	1.37	1.46	1.33	1.5	0.08
	After	1.51	1.42	1.31	1.43	1.51	1.5	1.23	1.43	1.38	1.41	0.08
Good	Before	2.44	2.41	**2.53**	2.7	**2.38**	**2.6**	**2.49**	**2.34**	**2.54**	**2.36**	0.10
	After	2.56	2.59	**2.79**	2.76	**2.69**	**2.82**	**2.86**	**2.62**	**2.82**	**2.73**	0.11
Guilty	Before	1.37	1.31	1.37	1.3	1.33	1.3	1.33	1.23	1.2	1.39	0.07
	After	1.41	1.26	1.18	1.32	1.39	1.33	1.23	1.32	1.21	1.3	0.07
Happy	Before	2.31	**2.32**	**2.47**	**2.57**	**2.26**	**2.5**	**2.47**	**2.17**	**2.34**	**2.33**	0.10
	After	2.47	**2.58**	**2.71**	**2.78**	**2.49**	**2.72**	**2.76**	**2.61**	**2.72**	**2.66**	0.11
Pleased	Before	2.52	2.51	2.72	**2.8**	**2.46**	2.78	**2.68**	**2.44**	**2.63**	**2.5**	0.11
	After	2.51	2.69	2.88	**3.0**	**2.67**	2.97	**2.91**	**2.8**	**2.94**	**2.83**	0.11
Satisfied	Before	2.57	2.56	**2.7**	2.77	2.5	2.81	**2.63**	**2.49**	**2.68**	**2.56**	0.11
	After	2.64	2.68	**2.91**	2.84	2.67	2.98	**2.88**	**2.74**	**2.88**	**2.8**	0.11
Unsafe	Before	1.39	1.29	1.29	1.37	1.4	1.34	1.28	1.23	1.28	1.43	0.07
	After	1.39	1.31	1.3	1.32	1.41	1.33	1.24	1.23	1.27	1.29	0.07
Warm	Before	1.9	1.76	1.8	1.99	1.89	1.86	1.77	1.72	**1.71**	1.93	0.09
	After	1.96	1.81	1.97	1.99	2.04	2.04	1.74	1.87	**1.92**	2.01	0.10
Worried	Before	1.38	1.34	1.31	1.37	1.42	1.3	1.26	1.29	1.22	1.38	0.07
	After	1.44	1.26	1.29	1.31	1.38	1.34	1.22	1.23	1.21	1.27	0.07

$^{\lambda}$Mean and standard error from 90 consumers on emotion responses based on a 5-point scale. Emotions were obtained before and after disclosing the SRC for the corresponding treatment.
^ Emotion responses did not differ between treatments (P>0.05) before or after stating the SRC.
Bold font indicates significant difference (mean difference >0.2) before and after disclosing the sodium content of the corresponding treatments (column) in the specific row (emotion response).

This positive bias or tendency towards positive emotion terms (Figure 3.2) has been referred to 'hedonic asymmetry,' attributed to the overall positive disposition that people have towards foods and to that food products are designed to be appealing (Desmet & Schifferstein, 2008). There were no differences between treatments both before and after stating the SRC. Responses are seemingly higher among positive (6) than negative (4) emotions. In addition, the lowest scores for positive emotions are only found before stating the SRC and mostly for treatment 8, while the highest counterparts are found only after stating the SRC and scattered between treatments 3 and 7. This mere trend suggests that treatment 8 did not favored positive emotions while better responses were observed among samples with slightly more salt.

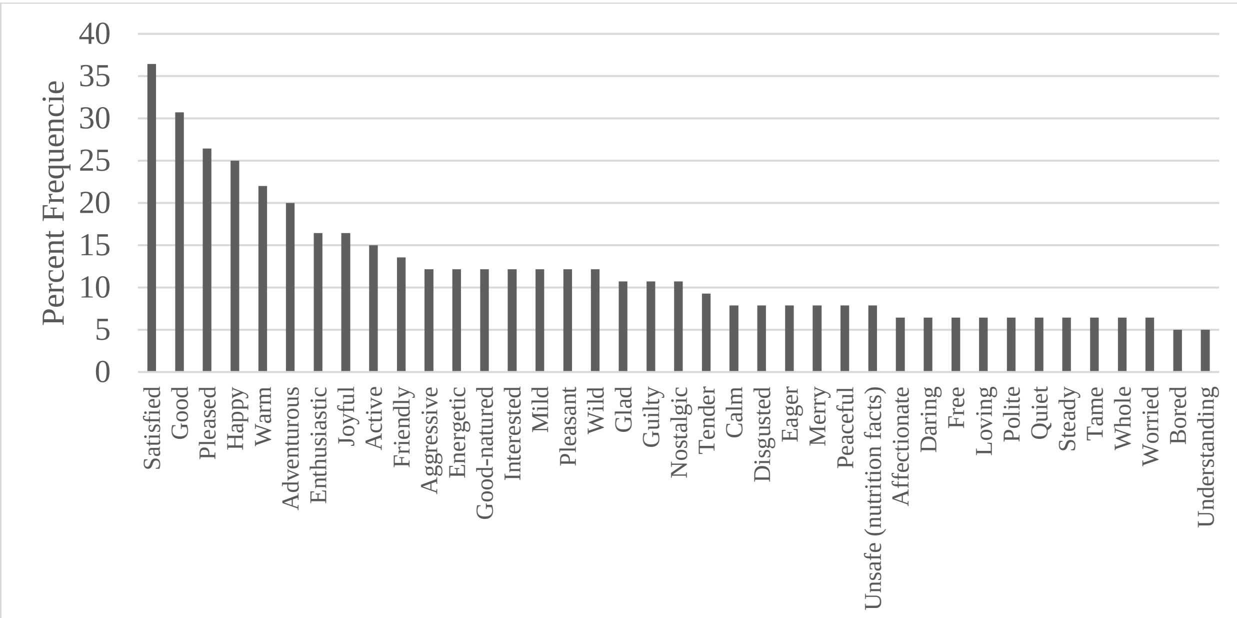

Figure 3.2 Emotion terms elicited by barbecue sauce. The online survey (N=90 participants)

Alternatively to conventional statistical analysis, a mean difference greater than 0.2 on emotion term responses reflects of practical importance (King, Meiselman, & Carr, 2013). Under this criterion, stating the SRC increased the scores of all 6 positive emotions for at least one treatment, whereas no such effect was observed among the negative emotions. *Happy* responses increased for all except for treatment 1, which reflect dominant or popular affective associations that consumers seem to be likely to express towards sodium reduced products.

All positive emotions increased for treatment 9 after signaling a 77.8% sodium reduction, [from highest to lowest; *happy*, *pleased*, *good*, *adventurous*, *warm*, and *satisfied* (0.38-0.2)]. Moreover, all except w*arm* increased for treatments 7, 8 and 10 displaying 65.1%, 73.6%, and 87.6% less sodium, respectively, with a maximum difference of 0.44 for h*appy* for treatment 8, followed by 0.37 for g*ood* on both treatments 7 and 10. In contrast, the highest response increase observed for treatment 1 was 0.16 for h*appy*. This could signify that an SRC of 38.93% is not adequately stimulating among consumers.

Current marketing strategies use labeling on product packages to persuade emotional responses from the consumers (Bialkova *et al.*, 2016). This is consistent with the emotion responses observed in this study after the consumers became aware of the sodium content of the samples. From a brain science perspective, however, the reward mechanism can generate "liking" and "wanting" for foods, referring to neural signals, which in turn influence dietary behaviors. The "liking" neuro signals are part of a large mechanism responsible for regulating arousal, appetite, and pleasure, whereas "wanting" mechanisms simply outgrow those of hedonics structures (Berridge *et al.,* 2010). Thus, the reward mechanisms associated with food can influence consumers' sensation and affection. Taken altogether, this approach could explain the increase in acceptability and PI responses described in Table 3.2, and the positive effect that stating the SRC had on positive emotions only in Table 3.3.

3.3.3. Factors affecting purchase intent predicted by logistic regression analysis

In this study, disclosing the SRC to the consumers had a positive effect judging from the increase in both acceptability and PI 'yes' responses (Table 3.1), and a concordantly increase in positive emotions only. For this reason, logistic regression analysis was performed to determine the associations between PI and emotion responses both before and after SRC, shown in Table 3.4. Before disclosing the SRC to the consumers, the emotion term *satisfied* was the only significant (P=0.0069) predictor for purchase intent, meaning that a one-unit increase, based on a 5-point scale, would increase the likelihood that the consumer would buy the barbecue sauce by 2.3 times. However, after disclosing the SRC, a one unit increase for that same emotion, *satisfied*, would now increase the purchase likelihood the barbecue sauce by up to 2.82. In addition, two more emotions became significant predictors of PI after disclosing the SRC to consumers, *adventurous* and *worried* with odds ratios of 1.5 and 0.34.

Table 3.4 Effect of SRC on PI by logistic regression analysis.

Parameters	Before		After	
	Pr > ChiSq*	Odds ratio	Pr > ChiSq*	Odds ratio
Adventurous	0.4337	1.17	**0.0471**	**1.5**
Good	0.1545	1.53	0.4734	1.2
Happy	0.4856	1.23	0.9154	1.03
Pleased	0.1344	1.65	0.7652	1.11
Satisfied	**0.0069**	**2.3**	**0.0008**	**2.82**
Warm	0.6743	0.9	0.1919	0.72
Disgusted	0.0553	0.38	0.3457	0.7
Guilty	0.6684	1.29	0.7451	1.19
Unsafe	0.1393	0.44	0.5209	1.35
Worried	0.8349	1.14	**0.0337**	**0.34**

*Statistically significant values in bold font (P<0.05).

It is important to highlight that, after stating the SRC to the consumers, *worried* became a significant predictor with the highest odds ratio. This result can be interpreted as that a one unit decrease on *worried* scores, based on the 5-point scale, would increase the likelihood of purchase intent for reduced and low-sodium barbecue sauces by 2.94 times.

At this point, after stating the SRC of the samples, the consumers are aware that they are evaluating reduced and low-sodium versions of the conventional product. The moment that the consumer becomes knowledgeable and aware of this information, the implications of communicating that information can result in an emotional response that in turn would influence their purchase intent towards a higher likelihood of choosing reduced and low sodium barbecue sauce. Generally speaking, this is consistent with the pattern observed on acceptability and PI responses (Table 3.2), and the overall increase of positive emotions only (Table 3.3).

Based on an Australian survey, shoppers that were mindful about the health concerns associated with high sodium intake would seek and read a specialized salt label found on food products to make informed decisions in regards to their health and wellbeing (Grimes *et al.,* 2009). Similarly, among adults who received clear health advice to reduce their sodium consumption, they modified their routines and associated behaviors, to some extent, to avoid or reduce their Na intake (Jackson *et al.*, 2016). However, the prevalence of changed behaviors was sustained longer among older adults who had acknowledged the advice from health professionals, than among younger participants between 18-24 years of age. This suggests that dietary habits from educated consumers are influenced by their orientation, by what they learn and can use to improve and promote their health, including changes in purchase preferences towards low sodium products, for example.

It is worth mentioning that health-related claims may not have the desired or intended effect and could also have a negatively affect. According to a survey from five northern countries, evaluating the impact of health related claims on bread, yogurt and pork, the consumers' perception and consideration of the product were deteriorated or adversely affected when presented with an informative statement claiming the corresponding health benefits of the product, in comparison to products that were otherwise presented without a claim or a statement of any sort. Moreover, the sole presence of said claim on health benefits was particularly affecting the perceived *naturalness* of the product (Lähteenmäki *et al.,* 2010).

3.4. Conclusion

First, consumers rated their liking of saltiness, bitterness and overall taste of reduced and low sodium barbecue sauce unaware of their sodium content. Results showed that there were no perceivable differences based on the consumers' liking of the perceived bitterness, saltiness and overall taste liking, thus a 90% NaCl reduction was achieved by 60% KCl and 30% Gly without variations on the taste perception. This was attributed to a combination of the inherent flavor profile of BBQ, salt and salt substitute mixtures, and the consumers' saltiness expectation as evoked from the color. The salt and salt substitute mixtures imparted enough saltiness despite their lower saltiness equivalence.

Alternatively, it is possible that the reduced and low sodium BBQ sauce developed for this study were similar enough to actual commercial products that the consumers' taste perception was assimilated into unconsciously evoked expectations. Meaning that while evaluating the BBQ sauce samples, they unwittingly let that the appearance, color, aroma and any sensory cues at the moment guided the ongoing physiological taste perception and had it assimilated into reminiscences of sensory profiles from recalled experiences.

Despite the lack of statistical significance, a trend showed that acceptability and PI responses increased after disclosing the sodium content of the reduced and low sodium BBQ sauce samples. This trend was in agreement with other studies on informative labels, emotions, and consumers' behavior, that support the premise that people welcome sodium reduction. Similarly, stating the sodium content of reduced and low sodium BBQ sauce samples increased the consumers' emotion response, particularly the sensation of being *happy*. Moreover, the consumers' responses at an affective level have been proven to influence behavior and could help motivate consumers to embrace or prefer healthier low-sodium diets.

Based on the logistic regression analysis (LRA), the emotion term *satisfied* was already a significant predictor of purchase intent for barbecue sauce. After stating the sodium claims to the consumers, the *adventurous* and *worried* also became significant predictors of purchase intent, thus indicating that the SRC stimulated consumers at an affective level which in turn influenced the consumers' intentions to purchase reduced and low sodium barbecue sauce products. This study observed that informative statements benefited the affective perception of reduced and low sodium BBQ sauce which in turn increased the likelihood of purchase.

Although hedonic responses along with acceptance and purchase intent all reinforced the deduction that there were no differences among treatments, it was noted that these belong to different realms of perception analysis. Meaning that taste perception belongs to a physiological process of assimilation of information through a network of specialized sensory channels and neurons, whereas the process of deeming a product acceptable or not and its subsequent purchase intention is carried out through a conscious perceptual process. This distinction was critical in order to appropriately conclude that the consumers' change in affective state after disclosing the sodium reduction claim, as a result of a cognitive process, was in accordance with the responses of acceptability and PI. Similarly, to conclude that the products were perceived to generate the same liking but more information about the consumers' perception was needed for a more thoughtful interpretation and conclusion of the effects of salt and salt substitute mixtures on reduced and low sodium barbecue sauce. Thus, the saltiness and bitterness perception from similar treatments were more appropriately evaluated and discussed in the next study.

Chapter 4. Sodium Reduction of BBQ Sauces Utilizing Salt and Salt Substitute Mixtures [NaCl, KCl, and Gly] and its Effect on Salty and Bitter Taste Perception

4.1. Introduction

High dietary sodium intake has been associated with high blood pressure, cardiovascular disease and kidney failure (Suckling & Swift, 2015). This has driven the development of sodium-reduced versions of conventional food products (Bobowski, Rendahl, & Vickers, 2015; Chokumnoyporn *et al.*, 2015; Desmond, 2006; Huynh *et al.*, 2016). Although well intended, when a health-oriented change takes place in the reformulation of a product, such as reducing salt, sugar, and fat, consumers may not welcome it, resulting in the failure of the new health-oriented product (Dijksterhuis, 2016). Thus, further reduction of dietary sodium remains needed and demands better understanding of the consumers' perception (Jackson *et al.*, 2016; Leshem, 2009b; Newson *et al.*, 2013; Suckling & Swift, 2015).

Several strategies to reduce sodium have focused on sodium chloride (NaCl), table salt, frequently used by consumers and manufacturers to impart salty taste on food products (Liem *et al.*, 2011). Dötsch *et al.* (2009) identified five categories for these strategies including the chemical substitution of salt, and the modulation of the perceived tastes through multisensory interactions. Potassium chloride (KCl) has been extensively studied as a salt substitute at up to 40% to 50% in several food products (Doyle & Glass, 2010; Kloss *et al.*, 2015; Kuo & Lee, 2014), although it renders a lesser saltiness intensity and imparts bitter and metallic off-flavors that become noticeable with increasing concentrations (De Souza *et al.*, 2013; Feltrin *et al.*, 2015; Torrico & Prinyawiwatkul, 2015). Similarly, up to 20% to 30% of salt was substituted with Glycine before evidencing sensory differences in meat products (Desmond, 2006; Gelabert *et al.*, 2003), yet has been reported to reduce the bitterness of KCl, thus posing a promising advantage towards reducing dietary sodium (Desmond, 2006; Khetra, Kanawjia, & Puri, 2016).

Food color may be used to indicate or even modulate the flavor of food products (Spence, 2010; Wan, Woods, Salgado-Montejo, Velasco, & Spence, 2015). Maga (1974) found that colors had physiological associations to some basic tastes; however, salty taste lacked strong associations with colors. In contrast, O'Mahoney (1983) indicates that respondents consistently associated salty taste to white color, which was not considered in the work by Maga. Similarly, Koch and Koch (2003) found positive associations between salty taste and white color only, when evaluating colors on soft drinks. Thus, recent research supports the possibility that multisensory effects may enable to modulate the saltiness perception of food products. Sukkwai et al. (2017) reported that increasing the colorant on a mayonnaise-based dipping sauce resulted in higher saltiness expectations. However, the effect that food color has on the process of taste perception remains unclear (Hidaka & Shimoda, 2014), which stresses the importance to clarify the associations between colors and tastes. From a physiological perspective, Stone *et al.* (2013) stated that each sense modality has specific receptors and neural pathways that are unlikely to crossover during the processing of information. Nevertheless, meaningful integration of this information happens into more complex structures in the brain. This consideration is critical for understanding the consumers' perception process as an inherently complex stimulus of senses which the brain combines and integrates the cooccurring information from the various senses with memories of similar nature.

Barbecue sauce is a popular marinade and condiment, often added to the meat to improve its flavor (Aramouni *et al.*, 2013). Sauces, such as barbecue, and served to improve the appearance, flavor, and texture of the food products (Akram *et al.*, 2012). According to the

National Nutrient Database for Standard Reference, the average serving size of barbecue sauce in the US contains approximately 15% of the daily sodium recommendations (USDA 2012), based on the 2,300 mg of Na per day (USDA, 2017). However, per Ahuja *et al.,* (2015), over half of the food products in the US exceeded FDA limits for sodium for healthy foods, where the sodium content of barbecue sauce had one of the widest variability across the study. Considering the popularity of barbecue sauce, its sodium content may pose health risk (Akram *et al.*, 2012), thus making it a candidate to explore sodium reduction technologies. Therefore, barbecue sauce was proposed as a good candidate for the evaluation of sodium reduction by means of salt and salt substitute mixtures and visual color cues.

The objective of this study was to evaluate and compare the perceived intensity of salty and bitter taste of reduced- and low-sodium barbecue sauces as determined by visual color observation vs. actual taste testing.

4.2. Materials and methods

4.2.1.Elaboration of Barbecue sauce

The base barbecue sauce was prepared as followed; A fraction of water (2% w/w) was incorporated into the tomato puree (40% w/w) (Cento Fine Foods, West Deptford, NJ) using a mixer (Globe, SP5-MIXER5QT, Dayton, OH, USA), then simmered and stirred constantly at 82 °C for 10 min. Next, a mixture of dry spices [0.05% ground black pepper, 0.5% garlic powder, (Great Value^{TM}, Wal-Mart Stores, Inc., Bentonville, AR), 0.04% ground cayenne pepper (Zatarin's, New Orleans, LA), and 0.8% mustard flour (Whole Foods Market Services, Inc., Austin, TX)] was incorporated and stalled for 5 min into the tomato puree, followed by a mixture of brown sugar (17% w/w) (Domino Foods Inc., Yonkers, NJ), white vinegar (18% w/w), molasses (4.8% w/w) (B&G Foods Inc., Parsippany, NJ), and Saladizer 234 gum (0.1% w/w;

hydrated with 3% w/w water) (Tic Gums, Belcamp, MD). Liquid smoke (3.5% w/w) (The Colgin Companies, Dallas, TX), and apple cider vinegar (9% w/w) were added last to preserve their aroma while minimizing its amounts. The mixture was heat treated for 30 min at 88 °C. The barbecue sauce base was placed into heavy-duty re-sealable plastic bags. A total of eight salt and salt substitute mixtures containing table salt (NaCl) (Great Value™, Wal-Mart Stores, Inc., Bentonville, AR), potassium chloride (KCl) (FCC grade, Extracts & Ingredients, LTD., Union, NJ, USA) and glycine (Gly) (Leico Medical, CAS#66-49-5, Glycine USP, 610823, Decatur, AL, USA) were used in the salt mixtures of this study, prepared according to Table 4.1.

Table 4.1 Ten formulations for reduced and low sodium barbecue sauce.

Treatment ID	%NaCl	%KCl	%Glycine	Na reduction (%)	Classification*
1	60	40	00	38.93	Reduced sodium
2	50	50	00	48.83	Reduced sodium
3	45	40	15	53.36	Reduced sodium
4	40	60	00	58.53	Reduced sodium
5	30	40	30	65.12	Reduced sodium
6	25	60	15	73.59	Low sodium
7	20	50	30	77.85	Low sodium
8	10	60	30	87.65	Low sodium

*Totaling 21mg of NaCl + KCl + Gly. *Classification according to the 21CFR101.61.

The barbecue sauce treatments were stored at 5 °C until the consumer study. According to the US FDA Nutritional Labelling Guidelines, 21 CFR 101.61 (FDA, 2015), the sodium content of treatments 1 to 5 (Table 4.1) were in compliance with the reduced-sodium labeling [at least 25% less sodium than the regular product available on the market (345 mg / 35 g per serving size or 10 mg / g, USDA, 2012)], and treatments 6 to 8 fit the requirements for the low-sodium labeling (<140 mg/50 g for small Reference Amounts Customarily Consumed).

The experimental design followed a three-component constrained mixture design. For this experiment, NaCl (X_1), KCl (X_2), and Gly (X_3), where the three component proportions summed to 1.0 or 100% (based on 21 mg NaCl+KCl+Gly) which was 2.1% of the BBQ formulation. A total of eight formulations were prepared for this research and all of them met either reduced or "low-sodium" criteria (no more than 140 mg of sodium per 50 g of sample) (21CFR101.61, CFR, 2017).

4.2.2. Color analysis of barbecue sauces

Three barbecue sauce samples were retrieved from each bag and measured in triplicate using a portable colorimeter (BC-10, Konica Minolta, Inc., Osaka, Japan). Results were reported as L*, a*, b*, and these values were used to calculate the Browning Index (BI), and total color difference (ΔE) was calculated using the unsalted barbecue sauce as a reference (L*=47.09, a*=3.26, b*=3.06). In an attempt to construct a reasonable parameter of reference for this study, the color of three commercial barbecue sauces from leading brands was used as a reference. The mean color values from these commercial products ranged from 46.4-46.6 for L*; 0.8-2.4 for a*; 1.2-2.4 for b*, and BI values from 3.8-8.9 (brands and corresponding data not shown for discretion). Based on the acknowledged variability among available commercial products and on the empirical measurements on leading brands of barbecue sauce, the barbecue sauce prototype and resulting treatments developed during this study was deemed an acceptable for our research purpose. The three commercial brands evaluated for comparison and reference were: Kraft Original Barbecue sauce (the Kraft Heinz company, Three Lakes Drive Northfield, IL, USA), Cattlemen's® Kansas City Classic Barbecue Sauce (French's foods; Reckitt Benckiser Inc., Parsippany, NJ, USA), and Sony's Sweet BBQ sauce (Sonny's Franchise Company, Winter Park, FL, USA).

4.2.3. Consumer testing

The research protocol for consumer testing was approved (IRB#HE15-9) by the Louisiana State University Agricultural Center Institutional Review Board. Consumer testing was conducted in the Sensory Analysis Laboratory, Animal and Food Sciences building, Louisiana State University, Baton Rouge, LA, USA. All evaluations were performed in partitioned sensory booths with cool natural lighting. The questionnaire was electronically presented to consumers, and data were collected using Compusense® *five* software (Compusense Inc., Guelph, Canada) software. All the participants thoroughly read and electronically signed a consent form to ensure they complied with the screening criteria including (1) being a regular consumer of barbecue sauce, (2) not allergic to any of the ingredients used in the barbecue sauces and (3) to be over 18 years of age. The consumer study followed a Balanced Incomplete Block Design and data collected by Compusense® *five* software (t=8, k=3, r=9, b=24). This way, each consumer evaluated 3 samples at the time and in a random order. Samples were presented in 2 oz. plastic cup with three-digit random code, 2×2×2cm cubes of steamed unsalted chicken breast as a carrier for the BBQ sauce, unsalted crackers and tempered water as a palate cleanser. A total of 240 consumers were recruited for this study (b*8 = 30*8 = 240 consumers).

Using a 3-point just-about-right (JAR) scale, panelists were asked to rate their perceived saltiness (1-Too Weak, 2-JAR, 3-Too Strong) and bitterness perception (1-None, 2-Moderate, 3-Too Strong) as evoked only from the color of the barbecue sauce samples. After completing their visual evaluation, they were asked to proceed and taste the samples using a cube of chicken breast as a carrier for the sauce and to rate their perceived taste intensity using the corresponding 3-point JAR scale.

4.2.4. Statistical analyses

Analysis of variance (ANOVA) and the Tukey's Honesty Significant Difference (HSD) tests were performed ($\alpha = 0.05$) to determine significant differences among the measured color values (L*, a*, b*, BI, and ΔE) using the SAS 9.4 software. The JAR data for salty and bitter taste assessments were converted into frequency counts and analyzed with the Cochran-Mantel-

Hansel (CMH) association test, Stuart-Maxwell marginal homogeneity test, and McNemar's test (Rothman & Paker, 2009).

4.3. Results and discussion

4.3.1. Color values of reduced and low sodium barbecue sauce

The color values from the BBQ sauces were analyzed regarding L*, a*, b*, Browning Index (BI), and total color difference (ΔE), as shown in Table 4.2. Differences across color values and treatments occurred, however, they were not associated with the salt substitute mixtures. Color values ranged from 47.6-48.3 for L*; 1.4-3.0 for a*; 2.7-3.6 for b*, and from 7.74-10.21 for BI and 0.67-2.12 for ΔE.

Table 4.2 Description of salt substitute treatments and instrumental color of barbecue sauces.

Treatment ID	Na Red. (%)	Proportion of salts mixtures (%)^ NaCl:KCl:Gly	Color				
			L *€	a *€	b *€	BI€	ΔE€
1	38.93	60 : 40 : 00	47.9 B	2.8 B	3.0 C	4.73	0.93 E
2	48.83	50 : 50 : 00	47.8 C	3.0 A	2.6 F	4.95	0.88 F
3	53.99	40 : 45 : 15	48.3 A	2.2 C	2.8 D	3.78	1.62 D
4	58.45	40 : 60 : 00	48.3 A	1.6 E	3.6 A	3.07	2.12 A
5	68.15	30 : 30 : 40	47.9 B	1.9 D	3.6 A	3.54	1.67 C
6	73.59	25 : 60 : 15	47.6 D	3.0 A	2.7 E	4.99	0.67 G
7	77.85	20 : 50 : 30	47.9 B	1.9 D	3.6 A	3.54	1.67 C
8	87.65	10 : 60 : 30	47.9 B	1.4 F	3.3 B	2.74	2.04 B

^Totaling 21mg of NaCl + KCl + Gly, 2.1% w/w.
€Values with the same letters are not statistically different (P>0.05) by columns. L*=Lightness. +a*=Color red. +b*= Color yellowness. BI= Browning Index in the CIELab color wheel. ΔE= Total Change of color. The core barbecue sauce was used as a reference for L*= 47.09, a*=3.26, b*=3.06. SD ranged from ±0.01 for L*; ±0.01 for a*; ±0.01 for b*; ±0.33 for BI; and ±0.002 for ΔE.

Despite its popularity, barbecue sauce lacks a standard of identity, which can explain why commercial BBQ sauces are one of the most variable products commercially available (Claybon & Barringers, 2001). For this reason, the only critical color value for the purpose of this study was ΔE value, which is then compared to a Just-Noticeable-Difference (JND) between color samples. Between tomato juice samples, distinctive visual differentiation occurred at ΔE values of at least 3.0 (Adekunte, Tiwari, Cullen, Scannell, & O'Donnell, 2010). In comparison, the highest ΔE in this study was 2.12, and thus the consumers are not likely to discern between treatments' colors. The lower the BI value, the darker the brownish color of the BBQ sauce samples, information may help give perspective to the data.

4.3.2. Perceived saltines and bitterness intensity from BBQ sauces

The consumers' responses to saltiness and bitterness perception as evoked solely by the brown color of the samples is summarized in Table 4.3 and displayed in complete detail in Tables 4.4 and 4.5. Results showed that neither saltiness or bitterness perception evoked from the brown color of the BBQ samples were visually discernible among treatments (Table 4.3), which is reasonable considering that the highest ΔE among treatments was lower than the JND value of 3 (Adekunte *et al.*, 2010). It is interesting that the results from the visual perception of saltiness and bitterness (P = 0.06 and P = 0.87, respectively) is apparently more variable than the results from the actual saltiness and bitterness perception (P = 0.359 and P = 0.999, respectively).

Table 4.3 Consumer evaluation results by tests mode responses

Test mode	Taste	
	Salty	Bitter
Visual taste expectations across treatments[f]	0.060	0.872
Perceived taste intensity across treatments[f]	0.359	0.999
Visual Assessment of Taste Perception vs. Perceived Taste Intensity[ħ]	**<0.001**	0.065

*Bold font indicates significant variation (P<0.05) for Cochran-Mantel-Haensel (CMH) test.
[f] Result based on 720 observations accounting for 80 true replications per treatment.
[ħ] Result based on 1,440 observations accounting for 80 replications per treatment per test mode.

It would be reasonable to expect the opposite, as in having observed more variability among the results from actual taste perception (lower p-values), than among the visually evoked perception of tastes (higher p-values). This leads back to the presumptions discussed at the end of section 3.3.1. To recapitulate, the sensory cues preceding the physiological taste perception can influence/modulate (in this case ameliorate or suppress the variability of responses) the overall taste perception. This would imply that higher cognitive mechanisms are overruling or at least influencing the consumers' physiological taste sensory perception of the sample. It was also pointed out that some limitations at the moment of that first consumer study did not favor the deeper or more radical interpretation of the results based or relying on an unknown magnitude of said cognitive effects if they were present at all. In this second study, however, it is possible to compare the responses from visually evoked tastes against the actual taste perception, as shown in table 4.3.

Based on the CMH test, there was strong evidence of a difference ($P<0.001$) between the two sets of responses of saltiness perception. This could be interpreted as in incongruence or divergence among the two modes of perception regardless of the treatments. A more detailed analysis is shown in table 4.4. Results indicate that the strong incongruence between the modes of saltiness perception was because the perceives saltiness intensity for treatments 1 and 8 were both less 'ideal' and somewhat weak compared to the expected saltiness intensity evoked by the brown color of the BBQ samples. These results are very reasonable considering that the consumers are evaluating the perceived saltiness intensity of reduced and low-sodium BBQ sauces.

Based on table 4.3, the actual saltiness perception among treatments was comparatively less variable (more likely to be similar) than the perceived saltiness evoked by the brown color of the BBQ sauces. However, based on table 4.4, the saltiness perception from treatments 1 and 8 was evidently weaker than its visually-evoked counterpart. Although seemingly counterintuitive, a possible explanation could be that when consumers visually estimating the saltiness intensity of the samples, they were relying on memories. According to Meiselman (2013), consumers are likely to idealize their conceptual image of a food product that was asked to evaluate. Moreover, the conceptually ideal product that they are imaging will be rated higher than when they would rate the actual product, and such effect can be extrapolated to emotional responses. This would explain why the saltiness intensity that consumers idealized from the appearance of the BBQ samples was rated higher than the actual salty taste of treatments 1 and 8, while not impeding or excluding that the actual saltiness perception across treatments was so similar. In addition, alluding to the cognitive effects of multisensory perception, it is possible that the idealized saltiness intensity modulated the subsequent consumers' actual salty taste perception of a given sample, which would have prevented that the saltiness perception from trts 1 and 8 were expose to be weaker than its counterparts, if the actual saltiness intensity of trts 1 and 8 was, in fact, weak as per table 4.4.

As mentioned in the previous section, it is important to keep in mind that the discussion and interpretation of these rather psychological effects and processes belong to an evidently abstract and amorphic realm that is too far away from objectivity and verifiable facts, in comparison to interpreting (for example) the relationship between perceived sweetness among aqueous solutions with systematically increasing amounts of sugar. Also, when discussing results in terms of cognition of affective responses, the relevance of food products as conceptualized by the consumer seems to gain more relevance and leverage than the formulation differences among treatments.

Regarding the visual and physiological evaluation of bitterness among BBQ samples, no effect was present in this study based on tables 4.3 and 4.5. This could simply mean that the bitter off-flavors from the salt substitutes were certainly insignificant in the flavor context of BBQ sauce and at the given concentrations. Alternatively, however, considering that some bitterness is desirable in food products of bold flavor such as chocolate or beer, which could make it possible that some bitterness is particularly tolerable in BBQ sauce.

Furthermore, referring to tables 4.2 and 4.3, the highest total color change value among treatments was very similar to the JND (2.12 vs. 3), while results of visually evoked saltiness perception were also very close to surpassing the critical value of statistic test ($P=0.06$). The saltiness perception varied relatively more than that of bitterness perception across all statistics (Table 4.3). These figures are, in a way, a reflection of how closely multisensory mechanisms can be related. However, if these observations are more than a coincidence, then it should be true that changes in BBQ sauce color should translate into congruent changes among saltiness expectations and even modulating the saltiness perception of samples with different colors and the same amount of salt. The next study addressed these ideas.

4.3.3. Assessment of brown color as an indicator of salty and bitter tastes of barbecue sauces

The saltiness perceptions evoked from color only was significantly different, incongruent, to the perceived salty taste intensity on Treatments 1 and 8 (Table 4.4). Treatments 1 and 8 showed incongruent salty taste perceptions compared to their visually evoked saltiness based on the CMH and the Stuart-Maxwell tests ($P < 0.05$). Based on the McNemar test, the "just about right" category responses for Treatment 1 decreased between taste expectations evoked from brown color, and the perceived saltiness (75.56% vs 57.78%; $P = 0.023$), while the "too weak" and the "too strong" category responses increased non-significantly (16.67% vs. 28.89% and 7.78% vs. 13.33%, respectively; $P > 0.05$). For Treatment 8, the "just about right" category responses decreased (81.11% vs 57.78%; $P = 0.004$) and the "too weak" category responses increased (10.00% vs 31.11%; $P < 0.001$) between taste expectations evoked from color and perceived saltiness, respectively. Previous studies have evaluated the effect of color on taste expectation (Sukkwai *et al.*, 2017), and on saltiness intensity (Chan & Kane-Martinelli, 1997; Gifford & Clydesdale, 1986; Maga, 1974), although there was not mention of congruency between color-evoked taste expectations and the taste perception of the samples in their studies.

Table 4.4 Saltiness perception based on the JAR responses as indicated by color vs. Taste.

Treatment ID	Mode	Too Weak	Frequency (%)ˠ Just About Right	Too Strong	CMH ℧	Stuart Maxwell^
1	Color	16.67	75.56*	7.78	**0.041**	**0.013**
	Taste	28.89	57.78*	13.33		
2	Color	8.89	77.78	13.33	0.191	0.166
	Taste	17.78	67.78	14.44		
3	Color	8.89	83.33	7.78	0.075	0.070
	Taste	15.56	68.89	15.56		
4	Color	13.33	73.33	13.33	0.818	0.803
	Taste	16.67	70.00	13.33		
5	Color	11.11	82.22	6.67	0.056	0.053
	Taste	22.22	66.67	11.11		
6	Color	25.56	64.44	10.00	0.650	0.600
	Taste	31.11	57.78	11.11		
7	Color	11.11	75.56	13.33	0.060	0.072
	Taste	24.44	62.22	13.33		
8	Color	10.00*	81.11*	8.89	**<0.001**	**<0.001**
	Taste	31.11*	57.78*	11.11		

ˠ Panelists' responses expressed as percent frequency per JAR-scale category: too weak, just about right, and too strong. **Bold** font indicates statistical significance (α=0.05). ℧ Cochran Mantel Hansel (CMH) and ^Stuart Maxwell tests. *Asterix indicates significant difference (P<0.05) based on McNemar test evaluating JAR category responses (column) between modes of perception (Color vs. Taste); see table 4.4 in Appendix B.

Shermer & Levitan (2014) stated that visual cues could lead flavor expectations to some extent. However, the resulting perception will not be modulated into recalled experiences if the stimuli are too incongruent or different from the evoked expectations as a result of the psychological and physiological contrast. In this study, the actual taste perception of the reduced and low sodium BBQ sauce samples were similar across the treatments. However, when analyzing the congruence between the visually evoked taste perception and the gustatory taste perception of the samples, results indicate variability, incongruence, for salty taste perception only (not bitter taste). This is reasonable as expected considering that the all samples contain at least 30% less sodium than the average commercial BBQ sauce in the US. However, this also implies that the consumers inferred on the saltiness intensity of the product based on the color of the samples. Previous publications have discarded the significance of color-taste associations and interactions for saltiness perception (Chan & Kane-Martinelli, 1997; Gifford & Clydesdale, 1986; Maga, 1974), but none evaluated the congruence between a visual cue and the perceived intensity.

The bitterness expectations evoked only by the brown color of the samples were congruent to the actual bitter taste perception of the panelists (Table 4.5). The taste expectations were consistently congruent ($P > 0.3$) to the perceived bitter taste intensity throughout all the treatments according to the CMH, Stuart-Maxwell, and McNemar tests.

Table 4.5 Bitterness perception based on the JAR responses as indicated by color vs. Taste.

Treatment ID	Mode	Frequency (%)[ɤ] None	Moderate	Too Strong	CMH [ʊ]	Stuart Maxwell^
1	Color	60.00	34.44	5.56	0.950	0.935
	Taste	62.22	32.22	5.56		
2	Color	52.22	42.22	5.56	0.679	0.533
	Taste	55.56	36.67	7.78		
3	Color	54.44	40.00	5.56	0.516	0.333
	Taste	60.00	32.22	7.78		
4	Color	60.00	35.56	4.44	0.951	0.937
	Taste	62.22	33.33	4.44		
5	Color	61.11	35.56	3.33	0.565	0.385
	Taste	61.11	32.22	6.67		
6	Color	63.33	33.33	3.33	0.592	0.605
	Taste	61.11	32.22	6.67		
7	Color	55.56	36.67	7.78	0.837	0.816
	Taste	56.67	37.78	5.56		
8	Color	61.11	33.33	5.56	0.681	0.660
	Taste	60.00	31.11	8.89		

[ɤ] Panelists' responses expressed as percent frequency per JAR-scale category: none, moderate, and too strong. No statistical differences (α=0.05). [ʊ] Cochran Mantel Hansel (CMH), ^Stuart Maxwell. Test evaluating JAR category responses (column) between modes of perception (Color vs. Taste); see table 4.4 in Appendix B.

Regarding bitterness perception, people apparently do not associate a red color with a bitter taste (Maga, 1974). More recent studies have observed that increasing red coloring in aqueous samples decreased the bitterness perception of flavored aqueous samples (Spence, Levitan, Shankar, & Zampini, 2010). This could explain that, despite the content of KCl, bitterness perception showed no evidence of variation nor incongruence, thus supporting that the bitterness suppression of KCl could be attributed to a multisensorial effect. For this reason, it could be possible that the associations between bitterness expectations evoked solely by the brown color of the samples and the perceived bitter taste intensity, were overshadowed by that of the saltiness perception, or that the bitter taste perception was assimilated into previous expectations due to perceptual constancy (Le Berrre *et al.*, 2013).

As the treatments evaluated in this experiment were similar, it was reasonable that the incongruence was not meaningful enough to evidence different saltiness perceptions, as shown in Table 4.3. The saltiness expectations evoked from brown color for Treatments 2 to 7 were consistently congruent to the actual salty taste perception ($P > 0.05$). According to Dijksterhuis, Boucon & Le Berre (2014), perceptual constancy may enable to reduce the salt content in food products if it looks, smells and has texture properties similar to those of the product that consumers are accustomed to, hence the perception may be assimilated into evoked experiences.

Treatments 1 & 8 had the highest and the lowest NaCl contents, respectively, thus it was reasonable to expect that they would show different salty taste perceptions, although it was not the case. In fact, it was observed that the salty taste perception was similar for all the treatments in spite of evidence of incongruence. Moreover, the perceived salty taste of Treatment 1 was different -incongruent- than its color-evoked salty taste expectations and that the perceived salty taste of Treatment 8 was weaker than its color-evoked salty taste expectations. This indicated that the brown color of the samples served as an indicator of the salty taste intensity for barbecue sauce, as perceived by the consumers' responses as evoked solely by the brown color of the samples which in turn aroused previous memories relatable to the product, including memories of its saltiness perception.

4.4. Conclusion

This study found that consumers associate the brown color of barbecue sauce with its saltiness intensity. In addition, the brown color of the barbecue sauce evoked reasonably consistent memories that influenced the consumers' expectations, which in turn influenced their perception of taste intensity of reduced and low sodium barbecue sauce that resulted in no discernable differences on saltiness and bitterness perceived intensities independently of the proportions of salt and salt substitutes. Furthermore, the color parameters observed in this study either concordantly matched or modulated the bitterness perception by means of assimilating the taste perception into the expectations evoked from the brown color of the samples, or by suppressing it due to cross-modal interactions between brown color and bitter taste perception.

Most importantly, this second study was inspired by the limitations and lacking areas of the first study. This led to a deeper exploration and evaluation of multisensory mechanisms influencing the gustatory flavor perception on consumers. These effects can be comparatively more abstract based on their physiological origins. However, they also enable the exploration of complex cognitive and affective associations that influence or even govern the perception of our food product and our surroundings.

These findings support that higher cognitive effects such as memory, information integration processes, and sensory perception of food products can be used to enhance the saltiness perception of food products, and subsequently be useful to decrease the sodium while minimizing adverse responses usually observed and associated with sodium reduced products. The implications of this reasoning support the previous findings, chapter 3, thus reinforcing that at least 90% salt may be substituted without perceivable variations in hedonic, and perceived taste intensity responses. This is important since it is higher than the results usually reported for salt substitute studies and more so since bitter taste off flavor was not perceivable despite substituting 90% of salt with 60% KCl and 30% Gly.

The results observed so far are based on a confounded effect regarding multisensory perception processes inherent to consumers, and the constant presence salty tasting compounds. Meaning that it, in order to isolate and better understand the relevance of color-taste associations on cross-modal interactions of flavor perception, it is necessary to independently vary the levels of color of the samples and the salt content. These observations are better evaluated discussed in the next chapter.

Chapter 5. Effects of Brown Color on Salty Taste Perception of BBQ Sauce With and Without Salt

5.1. Introduction

The National Salt Reduction Initiative (NSRI) initiated in 2009, being the first US effort to engage industry in lowering the population sodium intake. This coalition aimed to decrease the sodium in the US packaged and restaurant foods by 25% by 2014, thus lowering population sodium intake by 20%. Sodium reduction progress was monitored based on top-selling products from 61 food categories and compared to NSRI targets from 2009 till 2014 (Curtis *et al.,* 2016). Although more than half of the food categories failed to meet the targets, there were few product categories that met the sodium reduction target. These results from a federal agency helped highlight the need for better strategies and stronger commitment from the manufactures. A particularly difficult obstacle for reducing sodium strategies is that salt serves pleasant and hedonic properties at physiological and psychological levels (Morris *et al.,* 2008). However, nutritional information may influence the consumers into making healthier choices (Barreiro-Hurlé, Gracia, & De-Magistris, 2010; Kozup, Creyer, & Burton, 2003).

Food color can be used to indicate and even influence the flavor of food products (Spence, 2010; Wan *et al.*, 2015). From a physiological perspective, Stone *et al.* (2013)stated that each sense modality has specific receptors and neural pathways that are unlikely to crossover, yet meaningful integration of information occurs at deep and complex structures in the brain. This consideration is critical to understand the consumers' perception process as an inherently complex stimulus of senses which the brain combines with memories of similar scenarios and integrates the cooccurring information collected from the various senses.

Among early studies on color-taste associations of sodium, results were inconsistent if not contradictive. Maga (1974) stated that psychological associations between colors and tastes influenced the perception of some basic taste, except for salty taste, at least at the given conditions. Shortly after, O'Mahoney (1983) indicates that certainly salty taste was consistently associated with white color. Similarly, Koch and Koch (2003) evidenced positive associations between salty taste and white color only. For decades, a persistent interest seeks to better understand the cross-modal associations for salty taste and use them to enhance the saltiness perception in food products.

Sauces are used to enhance the taste and appearance of different food products (Akram *et al.* 2012). According to Choi *et al.* (2015), different types of sauces can become or reflect a signature flavor of a country's cuisine; this social aspect would certainly promote its consumption among the population. The National Nutrient Database for Standard Reference (USDA 2012), states that the average serving size of barbecue sauce imparts 15% of the daily sodium dietary recommendations, 2,300 mg of Na (USDA, 2017). According to Ahuja *et al.* (2015), the content of sodium on barbecue sauce products in the US was one of the most variables in the market. However, research studies on barbecue sauce are scarce, and there is no precedent work on the perceptions of saltiness and color intensity on barbecue sauce. Therefore, barbecue sauce was proposed as a good candidate for evaluating sodium reduction using different color cues. To our best knowledge, no previous researches have attempted to determine the effectiveness of brown color as a modulator for saltiness expectation and salty taste perception of barbecue sauces. Thus, the objective of this study was to evaluate the perception of salty taste in barbecue sauces as affected by different brown color shades and claims related to the content of sodium.

5.2. Materials and methods

5.2.1. Ingredients for barbecue sauce making

The ingredients used in this study were obtained from supermarkets in the area of Baton Rouge, USA, except for the gum. The list of ingredients used in this study are pure tomato puree, white vinegar, apple cider vinegar, ground black pepper, garlic powder, ground cayenne pepper, mustard flour, dark brown sugar, unsulphured molasses, liquid smoke, Saladizer 234 gum (Tic Gums, Belcamp, MD), salt (2.1% w/w), and black food colorant.

5.2.2. Barbecue sauce making procedure

The base barbecue sauce was prepared as followed. A fraction of water (2% w/w) was incorporated into tomato puree (40% w/w) by a mixer (Globe, SP5-MIXER5QT, Dayton, OH, USA), then simmered and stirred constantly at 180°F for 10 min using a kettle (Globe, SP5-MIXER5QT, Dayton, OH, USA). Next, a mixture of dry spices (0.05% ground black pepper, 0.04% ground cayenne pepper, 0.8% mustard flour and 0.5% garlic powder) was incorporated and stalled for 5 min, followed by a mixture of brown sugar (17% w/w), white vinegar (18% w/w), molasses (4.8% w/w) and hydrated gum [0.1% w/w hydrated gum (3% w/w water)] Finally, liquid smoke (3.5% w/w) and apple cider vinegar (9% w/w) were added. The batch was heated for 30 min at 190°F. The base barbecue sauce was poured hot into heavy-duty sealable PVC plastic bags and stored at 5°C. According to the US FDA Nutritional Labelling Guidelines, 21 CFR 101.61 (FDA, 2015), the sodium content of unsalted prototypes met the qualification for low-sodium labeling (<140 mg/50 g for small Reference Amounts Customarily Consumed).

5.2.3. Color analysis of barbecue sauces

Color measurements were performed using a colorimeter (BC-10, Konica Minolta, Inc., Osaka, Japan), and results were reported as L*, a*, b*, Browning Index (BI), and total color difference (ΔE), which was calculated using unsalted barbecue sauce as a reference (Table 5.1).

5.2.4. Consumer testing

The research protocol for the use of human subjects was approved (IRB# HE15-9) by the Louisiana State University Agricultural Center Institutional Review Board. Consumers (n = 225) were recruited among the population of the Louisiana State University, Baton Rouge, Louisiana, USA. The product evaluation took place in partitioned sensory booths illuminated with cool, natural, fluorescent lights. The temperature inside the sensory lab was maintained around 75°F with slight negative air pressure to remove odor from the sample preparation area. Compusense® *five* software (Compusense Inc., Guelph, Canada) software, was used to present the questionnaire to consumers and to collect the data. All the participants thoroughly read and electronically signed a consent form to ensure they complied with the screening criteria including (1) being a regular consumer of barbecue sauce, (2) not allergic to any of the ingredients used in the barbecue sauces and (3) to be over 18 years of age Consumers were first asked to evaluate the perceived saltiness of the samples as evoked solely by the color using a 3-point just-about-right (JAR) scale (1-Too Weak, 2-JAR, 3-Too Strong). After completing the visual assessment of saltiness perception, consumers were asked to taste the BBQ samples using chicken breast cubes as a carrier for the samples; they rated their saltiness liking using a 9-point scale (1-Dislike extremely, 5-Neither like nor dislike, 9-Like extremely) and the perceived saltiness intensity using a 3-point JAR scale. Consumers were then informed about the sodium content of the samples and were asked to rate yet again their saltiness liking and perceived saltiness intensity using the 9-point scale and the 3-point JAR scale, respectively.

5.2.5. Experimental design

The BBQ prototypes followed a 2×3 factorial combination of salt levels (salted vs. unsalted) and three brown color levels (light, medium and dark), thus 6 treatments total (Table 5.1). The sodium content of the samples was either equal to the average barbecue sauce in the US (USDA, 2012) or absent and labeled as "low-sodium" (21CFR101.61, CFR, 2017). The three brown color levels were fixed using black food colorant. BBQ samples contained either no colorant, 0.001 (w/w%) or 0.002 (w/w%) for Light, Medium, and Dark brown levels, respectively. The consumer test followed a Balanced Incomplete Block Design developed with Compusense® *five* software (t=6, k=2, r=5, b=15). All 6 treatments were evaluated in systematical and random combinations of 2 at the time per consumer. BBQ samples were presented in 2 oz. plastic cup with three-digit random code, 2×2×2cm cubes of steamed unsalted chicken breast as a carrier for the BBQ sauce, and unsalted crackers and tempered water as a palate cleanser. A total of 225 consumers were recruited for this study (b*15 = 15*15 = 225 consumers).

5.2.6. Statistical analyses

Analysis of variance (ANOVA) and the Tukey's Honesty Significant Difference (HSD) tests were performed ($\alpha = 0.05$) to determine significant differences in color values (L*, a*, b*, BI, and ΔE) among treatments using SAS 9.4 software. The JAR data from the consumer test were analyzed with Cochran-Mantel-Hansel (CMH) association test, the Stuart-Maxwell marginal homogeneity test, and McNemar test ($\alpha = 0.05$) (Rothman & Parker, 2009).

5.3. Results and discussion

5.3.1. Instrumental color and saltiness expectations evoked from the brown color

Results for L*, a*, b*, browning index (BI) and total color difference (ΔE) values are shown in Table 5.1. Browning index values decreased while ΔE increased with higher colorant concentration. Thus, the lowest BI values correspond to Dark brown samples. Browning Index is correlated to a* value and is intended to objectively measure the purity of the brown color (Perez-Gago, Serra, & Del Río, 2006; Zambrano-Zaragoza *et al.,* 2014). Regarding ΔE, values ranged from 0.2-0.41 for Light brown samples, from 1.53-1.81 for Medium, and 3.35-3.43 for Dark brown samples. According to Adekunte et al. (2010), ΔE values between 1.5 and 3 are likely to be visually discernible. Based on the ΔE values of the treatments in relation to the JND range, consumers will be able to differentiate between brown color levels.

Table 5.1 Treatment description and color values

Treatment description			Instrumental color values				
Brown Color	Na Label	ID	L *€	a *€	b *€	BI€	ΔE€
Light	Low Na	1	47.30 ± 0.15 AA	3.48 ± 0.16 A	3.20 ± 0.00 A	5.83 ± 0.22 A	0.20 ± 0.08 E
Light	Regular	4	47.03 ± 0.12 BA	3.24 ± 0.15 B	3.08 ± 0.12 B	5.49 ± 0.24 B	0.41 ± 0.14 D
Medium	Low Na	2	46.93 ± 0.20 BC	2.12 ± 0.15 C	2.63 ± 0.11 C	3.74 ± 0.21 C	1.53 ± 0.17 C
Medium	Regular	5	46.80 ± 0.05 CA	1.89 ± 0.06 D	2.49 ± 0.03 D	3.37 ± 0.06 D	1.81 ± 0.06 B
Dark	Low Na	3	46.10 ± 0.01 EA	0.67 ± 0.04 E	1.83 ± 0.04 E	1.42 ± 0.07 E	3.35 ± 0.05 A
Dark	Regular	6	46.26 ± 0.18 DA	0.58 ± 0.04 E	1.70 ± 0.05 F	1.25 ± 0.06 E	3.43 ± 0.07 A

€ Mean ± Standard Deviation, same lettered values are not statistically different based on ANOVA at α=0.05.
L*=Lightness. +a*=Color red. +b*= Color yellowness. BI= Browning Index derived from L*, a*, and b* values. ΔE= Total change of color calculated using light brown unsalted barbecue sauce as a reference (L*= 47.30, a*=3.48, b*=3.20).

The perceived saltiness responses were significantly different among brown color levels, as shown in Table 5.2. Dark brown color evoked significant differences regarding strictly visually evoked saltiness responses when compared to Medium and Light brown samples (P=0.001, and P=0.011, respectively; data not shown). In addition, Medium and Light brown samples also evoked significant differences regarding the expected salty taste intensity (P=0.03, data not shown). Moreover, JAR category responses show a direct relationship between the darkening of brown levels and perceived saltines responses, that is, dark brown samples had the most "too strong" responses (22), and so on for medium brown samples with the highest JAR responses (80.67), and light brown samples with the highest "too weak" responses (21.33) (Table 5.2), and thus suggesting that there is a direct and specific association between the darkening of the brown color of BBQ sauces and the expected saltiness intensity. Medium brown samples evoked the most idealized perception of saltiness among the three brown levels.

Table 5.2 Stratified CMH test on perceived saltiness evoked by brown color of BBQ sauce

Color Level	Frequency (%)[ɣ]			CMH
	Too Weak	Just-About-Right	Too Strong	
Light	21.33	67.33	11.33	
Medium	12.00	80.67	7.33	**<0.001** [f]
Dark	12.00	66.00	22.00	

[ɣ] JAR-category responses expressed as percent frequency: too weak (TW), just about right (JAR), and too strong (TS). **Bold** font indicates significant (P<0.05) differences among color levels based on Cochran-Mantel-Hansel test (N=450).

Color-taste associations are not limited to brown color on BBQ sauce. Clydesdale *et al.* (1992) highlighted the importance of evaluating cross-modal association in a relevant and ecological context and suggesting that researchers should have or seek for an underlying yet robust reason to associate a given color with a given taste in a given food product rather than study random combinations. Considering the simultaneous popularity and high variability of commercial BBQ sauces, it could be logical to imagine any regular consumers encounter and try a plethora of taste profiles and colors of barbecue sauces. In such hypothetical case, said consumer would collect copious amounts of sensory information from a variety of modes of perceptions and intensities. Later on, those experiences would become memories used to construct expectations of various attributes and at various intensities. Thus having generated a database for cross-modal associations, however imaginary and with the only purpose of illustrating this discussion.

5.3.2. Color-taste association and salty taste perception of BBQ sauce

Paired comparisons of the gustatory saltiness perceptions are shown in table 5.3. Results show significant variations in the perceived saltiness between BBQ samples of a different color but with the same content of salt. For example, the perceived saltiness from Dark brown BBQ sauce was different from that of Light brown samples ($P = 0.047$) despite having the same amount of salt (Table 5.3).

Table 5.3 Effect of brown color on perceived saltiness on regular and low-sodium samples.

Sodium levels	Brown color levels			Treatment ID			Stuart Maxwell*
Low Na	Medium	vs	Dark	2	vs	3	**0.027**
	Light	vs	Dark	1	vs	3	0.635
	Light	vs	Medium	1	vs	2	0.111
Regular Na	Medium	vs	Dark	5	vs	6	0.305
	Light	vs	Dark	4	vs	6	**0.047**
	Light	vs	Medium	4	vs	5	0.069

*Bold font indicates statistical significance (P<0.05) for Stuart Maxwell test comparing treatments of different brown color levels at the same sodium level (N=150).

Based on tables 5.1 and 5.2, the differences of saltiness intensity as evoked solely by different color levels can be logically attributed to the (ΔE) between brown color levels and to the color-taste association between brown color and salty taste on barbecue sauce. This means that the saltiness perception evoked by the color of the samples will correlate to a large enough ΔE (>JND). Based on tables 5.1 and 5.3, the difference of perceived saltiness among samples with the same salt content can be logically attributed to a cross-modal effect driven by the expected saltiness as evoked from the brown color levels but is no longer correlated to ΔE. Based on abductive inference, taste modulation is due to cross-modal effect but no longer related to ΔE. It is possible that it is dependent to a conceivable distance between expectation and true perception of tastes. This is consistent with the findings from Dijksterhuis and others (2014), and

LeBerrre and others (2013), although in our study the modulation of taste perception was not dependent on the sensory cues from the first impression, but the reminiscence of previous barbecue sauce tasting experiences as evoked from the brown color levels of the samples.

The salty taste differences between treatments 2 and 3 (P=0.027) can be explained as the overall change among the JAR category responses, meaning that between medium to dark brown low-sodium samples, there was a 6.66% decrease in 'too weak', an increase of 14.66% in 'JAR,' and a decrease of 8% on 'too strong' responses [(54.66 vs. 48.00; 33.34 vs. 48.00; and 12.00 vs. 4.00, respectively (Table 5.4)]. Similarly for the salty taste differences between treatments 4 and 6 (P=0.047), between light to dark brown regular-sodium samples, there was a decrease of 1.36% in 'too weak', and of 5.32% in 'JAR,' and an increase of 6.68% on 'too strong' responses [16.02 vs. 14.66; 79.98 vs. 74.66; and 4.00 vs. 10.68, respectively (Table 5.4)]. Based on McNemar test, however, the treatment differences per category responses were not significantly different. These results showed that saltiness taste can be modulated by brown color visual cues, although future studies should consider smaller intervals between the experimental factors of color intensity and salt content to understand better the results observed in table 5.3.

5.3.3. Congruency between color-evoked saltiness expectations and perceived salty taste intensity

Visually evoked saltiness and actual saltiness perception responses were compared to determine the congruence between modes of perception among treatments (Table 5.4). Light, Medium, and Dark brown samples showed color-evoked saltiness expectations to be incongruent for low-sodium samples, based on CMH and Stuart Maxwell tests (P<0.05). However, only Light (1) and Medium brown (2) samples were significantly (McNemar test, P<0.05) less salty than what the consumers' saltiness perception as evoked by their respective brown color, unlike Dark brown (3) samples (P>0.05). McNemar test results indicate that the "just about right" category responses decreased (P < 0.05) while "too weak" responses increased (P < 0.005) for low-sodium Light and Medium brown samples, treatments 1 and 2 respectively. Thus, the incongruence observed for this sample was attributed to a distinctively weak salty taste. Unlike treatments 1 and 2, Dark brown (3) samples influenced the consumers' perception in a way that category response differences were not significant per McNemar test (P > 0.05).

Table 5.4 Congruency among expected saltiness perception evoked on brown color and perceived salty taste intensity.

Treatment Id.	Mode	Frequency (%)[ˠ] Too Weak	Just About Right	Too Strong	CMH [ʊ]	Stuart Maxwell^
1	Color	25.30*	65.34*	9.36	**<0.001**	**<0.001**
	Taste	52.00*	42.66*	5.34		
2	Color	13.32*	82.68*	4.00	**<0.001**	**<0.001**
	Taste	54.66*	33.34*	12.00		
3	Color	13.34	66.68	19.98	**<0.001**	**<0.001**
	Taste	48.00	48.00	4.00		
4	Color	17.32	69.36	13.32	0.113	**<0.001**
	Taste	16.02	79.98	4.00		
5	Color	10.68*	78.64*	10.68	0.169	**0.008**
	Taste	21.34*	72.00*	6.66		
6	Color	10.66	65.34	24.00	0.092	0.235
	Taste	14.66	74.66	10.68		

[ˠ] Panelists' responses expressed as percent frequency per JAR-scale category: too weak, just about right, and too strong. **Bold** font indicates statistical significance (α=0.05). [ʊ] Cochran Mantel Hansel (CMH) and ^Stuart Maxwell tests. *Asterix indicates significant difference (P<0.05) based on McNemar test evaluating JAR category responses (column) between modes of perception (Color vs. Taste); see table 4.4 in Appendix B.

This results imply that the consumers' perception of the salty taste intensity from treatment 3 was not evidently weaker as was the case for the other samples with no salt added, treatments 1 and 2. Thus, the Dark brown color led the consumers' perception towards the visually evoked salty taste intensity and making the lack of salt content less evident than Light and Medium brown colored samples.

For regular sodium samples, only Dark brown (6) samples delivered a saltiness perception consistently congruent to the evoked saltiness expectations only from the color of the sample, based on CMH, Stuart Maxwell, and McNemar tests (P > 0.05). However, responses for

Light brown (4) and Medium brown (5) samples delivered incongruent saltiness perceptions based on Stuart Maxwell test ($P<0.05$). From a statistical perspective, CMH test has a low power for detecting associations in the opposite direction (SAS® Institute Inc., ND), while the Stuart-Maxwell test of marginal homogeneity may complement CMH test results (Sun and Yang, 2008). As such, the statistical inconsistency between CMH and Stuart Maxwell tests may be attributed to the inherent lesser power of the CMH test. Thus the saltiness expectations evoked from Light and Medium brown colored samples were deemed incongruent to the perceived salty taste intensity of regular sodium samples.

Moreover about treatment 5, McNemar test results indicate that the "just about right" category responses decreased ($P < 0.05$) while "too weak" responses increased ($P < 0.005$). Thus, the Mark brown color led the consumers' perception towards the visually evoked salty taste intensity and rendering the physiological taste perception weaker than Light and Dark brown colored samples. As such, color-taste associations modulated the consumers' saltiness perceived intensity on low and regular sodium BBQ sauce samples.

In this section, saltiness perception of Dark brown colored samples behaved differently than its counterparts with the same content of salt. Among low-sodium BBQ sauce, Dark brown (3) samples led the consumers' perception towards the visually evoked salty taste intensity thus making the lack of salt less evident. Among regular sodium BBQ sauce, Dark brown (6) samples showed no evidence of incongruence ($P > 0.05$, CMH, Steward Maxwell, and McNemar tests), unlike its counterparts treatments 4 and 5. In the previous section, Dark brown samples provoked different saltiness perception to Medium, and Light brown samples among regular sodium and low-sodium BBQ sauce, respectively ($P = 0.027$, and $P = 0.047$, respectively) (Table 5.3).

From a physiological perspective, Stone *et al.* (2013) stated that each sense modality has specific receptors and neural pathways that are unlikely to crossover during the process of perception information, although meaningful integration of this information occurs further into more complex structures in the brain. Meaning that, even though different sensory stimuli (e.g., sight and taste) are internalized through different and independent pathways, it is possible to modulate the consumers' perception when the incoming stimuli are combined and processed by the brain, as part of an inherently complex process.

In this study, the brown color of the samples affected the saltiness expectations (Table 5.2), and the perceived salty taste intensity among samples with the same sodium content (Table 5.3). Furthermore, Dark brown colored samples behaved differently than its counterparts with the same content of salt when evaluating congruence between modes of responses (Table 5.4). Compared to the previous study, reduced and low-sodium barbecue sauces delivered congruent stimuli (Table 4.4) for samples with BI values ranging from 2.74-4.95 (Table 4.2), whereas regular sodium Dark brown samples, with BI value of 1.25 (Table 5.1), was the only treatment perceived to deliver congruent stimuli (Table 5.4). Altogether, this underlines the mechanism of a cross-modal interaction where the brown color of the barbecue sauce modulated the consumers' visually evoked expectation of taste, as reflected by congruence analysis, and subsequently their perceived saltiness intensity.

5.3.4. Effect of sodium claim on salty taste perception.

Stating the health claim decreased the "too weak" and "too strong" while increasing the "just about right" category responses for all low-sodium barbecue sauce regardless of the brown color level. Communicating the health claim related to dietary sodium improved the perceived salty taste intensity for low-sodium Medium brown (2) barbecue sauce samples only (Table 5.5), based on CMH, Stuart Maxwell and McNemar tests (P<0.05). Furthermore, the “just about right” category responses of low-sodium Medium brown barbecue sauce samples increased (33.33% vs. 45.33%; P=0.025) after disclosing a health claim associated with dietary sodium along with the sodium content of the BBQ sauce samples.

Table 5.5 Effect of the sodium reduction claim on the perceived salty taste intensity.

Treatment Id.	Mode	Frequency (%)[ɣ] Too Weak	Just about right	Too strong	CMH [ʊ]	Stuart-Maxwell^
1	Before	52.02	42.66	5.34	**0.0037**	0.106
	After	44.00	52.00	4.00		
2	Before	54.66	33.36*	12.00	**0.0001**	**0.021**
	After	45.33	45.33*	9.33		
3	Before	48.00	48.00	4.02	**0.0001**	0.223
	After	44.00	53.33	2.67		
4	Before	16.02	79.98	4.02	0.1135	0.189
	After	14.67	77.33	8.00		
5	Before	21.36	72.00	6.66	0.1689	0.223
	After	18.67	73.33	8.00		
6	Before	14.64	74.64	10.68	0.0928	0.082
	After	9.33	78.67	12.00		

[ɣ] Panelists’ responses expressed as percent frequency per JAR-scale category: too weak, just about right, and too strong. **Bold** font indicates statistical significance (α=0.05). [ʊ] Cochran Mantel Hansel (CMH) and ^Stuart Maxwell tests. *Asterix indicates significant difference (P<0.05) based on McNemar test evaluating JAR category responses (column) between modes of perception (Before vs. After); see table 4.4 in Appendix B.

Health statements have been observed to affect the taste perception of products depending on the food category, perceived product healthfulness, and the consumers’ health concerns. Bialkova et al. (2016), compared the perceived salty taste before and after presenting the health claim and sodium content to the consumers and observed that this lined the panelists’ responses into an amended salty taste perception, meaning that stating the health and sodium related information improved the consumers’ perception of salty taste. Liem *et al.* (2012) observed that labels such as “reduced in salt” on soup disfavored the taste perception for consumers who prioritized taste over healthiness attributes of the product while Bialkova *et al.*

(2016) observed that the perceived tastefulness of potato chips and cereal bars decreased when the front of pack (FOP) featured a nutritional label indicating 30% less fat, and 30% less sugar, respectively. These authors attributed this to that consumers may anticipate a decreased tastefulness caused by the alleged reduction of fat, salt or sugar. However, this effect was moderated by the products' perceived healthfulness and the consumers' health concerns. In contrast, Poonnakasem et al. (2016,) observed that health benefit statements increased the overall liking, purchase intent, and response of positive emotions (*calm, good, happy, pleased* and *satisfied*) on panelists evaluating sponge cake prepared with different oils, although this study did not focus on salty taste perception.

In a previous chapter (section 3.3.2), stating the sodium reduction claim (SRC) of reduced and low sodium barbecue sauce increased the consumers' positive emotion responses, particularly for low sodium BBQ sauce (Table 3.3). It is possible that stating the health claim and sodium content of Light, Medium, and Dark low-sodium BBQ sauce increased the consumers' sensation of positive emotions, which in turn improved the salty taste perception of the samples. On a recent study comparing two flavors of ice cream, it was observed that the overall hedonic responses increased with the increasing sensation of *satisfaction* with sport games outcomes (Noel & Dando, 2015). Furthermore, the less liked ice cream sample was liked significantly higher. Sweet and sour taste varied significantly based on the panelists' ratings of satisfaction, where increasing ratings in satisfaction resulted in higher sweet intensity perception and diminished sour intensity perception, thus generally enhancing the hedonic ratings of the product despite being the lesser liked product. By this, informative statements may improve or diminish the hedonic taste perception depending on the concerns or rewards implied from the consumers' standing point.

5.4. Conclusion

This study observed that the brown color of BBQ sauces modulated the consumers' perception of salty taste intensity among BBQ samples with the same salt content due to color-taste associations that led to a cross-modal interaction. The "sodium reduction" claim favored the saltiness perception of low-sodium barbecue sauces. Disclosing the sodium statement improved the perceived salty taste intensity of low-sodium samples by counteracting, to some extent, the weak saltiness intensity of low-sodium BBQ sauce. These findings imply that manufacturers could manipulate the brown color to develop healthier barbecue sauces with reduced sodium.

Chapter 6. Summary and Conclusions

6.1. Summary and conclusions

The adverse health effects associated with the excessive sodium intake have reached pandemic proportions. Based on an ever-growing number of publications, it is understood that the average salt consumption is disproportionate to any health reference or standard. Through systematic and thorough studies, it is well known that the factors that promote the salt consumption include physiological and behavioral responses, as well as external factors such as food manufacturing trends, and limited availability of low sodium products. Considering that sodium consumption is a dietary matter, food scientists, manufacturers, and health professionals face the need to find the means to prevent further harm. Thus, professionals and technologies from several backgrounds are set to explore and develop strategies to continue to reduce the sodium content in food products and help people enjoy a healthier future. The general objective of the present research compilation was to explore sodium reduction technologies that could be adopted by the food industry without affecting the consumers' satisfaction.

For Study I, regarding saltiness liking, results showed that it was possible to cut down up to 90% of salt with 60% KCl, and 30% Gly in the BBQ sauces. Acceptability and Purchase Intent responses supported the hedonic results, which were very similar among treatments and led to realize that the consumers' responses could have been modulated through psychological mechanisms, perhaps in synergy with the salt and salt substitute mixtures rather than being the sole representations of the different formulations. The planning of Study II was inspired by the limitations in Study I. It is worth to point out that the treatments were similar but a change in scope enabled to discover sublet but crucial results. Thus concluding that the treatments evoked similar saltiness expectations as well as similar gustatory saltiness intensities but sensory cues, like its appearance and aroma, may have modulated or biased the consumers responses of taste since the sensory cues were very similar among treatments. There are limited studies addressing the combined effect of salt substitutes and cross-modal effects as technologies to help reduce the content of sodium with minimal alteration of the food product formulations and with minimal alteration of the consumers' responses. Thus, the main contribution of this study was to observe and document the use of salt substitutes and color-taste associations, and its effect to modulate the saltiness perception of barbecue sauce. The next study aimed to isolate the effect of sensory cues.

Study III aimed to modulate the sensory cues from the BBQ sauce, rather than its formulation, and evaluate how the appearance affected the saltiness expectation, and the gustatory saltiness perception at two levels of saltiness. The results confirmed that the consumers' saltiness expectation was associated with darkening levels of brown color, and that such association led to modulate the consumers' salty taste perception at the same content of salt. However, some requirements must be met or considered for this effect to take place, such as congruence between the type and intensity of the sensory cue, the taste, and the product.

Taken together, it was most interesting to realize how much can different mechanisms interfere with the consumers' perception of food products. Factors other than food product formulation were found to enhance the perceived intensity of salty taste of reduced and low sodium BBQ sauce with minimal detriment of the consumers' responses. In addition, disclosing the sodium content of the samples were found to enhance the consumers' affective perception of reduced and low sodium barbecue sauces which in turn improved their purchase intentions.

On a separate note, it is worth to point out that the design and adaptations made to the series of experiments performed in this research was inspired on the suggestions from renowned sensory scientists addressing the future needs of the field. The food industry and the consumers are changing, and so should the research technique from Sensory and Consumers Researches. Authors encouraged the readers to think about the early development sensory evaluation, from its origins as a method that conceivably grew into a technology, and how it has continuously adopted a multidisciplinary approach to help respond new research problem. The forthcoming research work should seek to broaden the use of typical tests, and methods to analyze data, and to be creative when approaching new problems. There is growing interest in better understanding individual differences and the effects of context on the sensory perception of food products. There is a need of knowledge that would help understand the role of previous experiences unique to each consumer, and environmental factors affect not only the evaluation of the product but how it may affect the consumers' behavior. The findings of this research contribute to better understand the use of sensory cues to modulate the expectations and in turn the gustatory saltiness perception of reduced and low sodium products.

Appendix A: IRBD Research Consent Form

LSU AgCenter Institutional Review Board (IRB)
Dr. Michael J. Keenan, Chair
School of Human Ecology
209 Knapp Hall
225-578-1708
mkeenan@agctr.lsu.edu

Application for Exemption from Institutional Oversight

All research projects using living humans as subjects, or samples or data obtained from humans must be approved or exempted in advance by the LSU AgCenter IRB. This form helps the principal investigator determine if a project may be exempted, and is used to request an exemption.

- Applicant, please fill out the application in its entirety and include the completed application as well as parts A-E, listed below, when submitting to the LSU AgCenter IRB. Once the application is completed, please submit the original and one copy to the chair, Dr. Michael J. Keenan, in 209 Knapp Hall.

- A Complete Application Includes All of the Following:
  (A) The original and a copy of this completed form and a copy of parts B through E.
  (B) A brief project description (adequate to evaluate risks to subjects and to explain your responses to Parts 1 & 2)
  (C) Copies of all instruments and all recruitment material to be used.
    - If this proposal is part of a grant proposal, include a copy of the proposal.
  (D) The consent form you will use in the study (see part 3 for more information)
  (E) Beginning January 1, 2009: Certificate of Completion of Human Subjects Protection Training for all personnel involved in the project, including students who are involved with testing and handling data, unless already on file with the LSU AgCenter IRB.
  Training link: (http://grants.nih.gov/grants/policy/hs/training.htm)

1) Principal Investigator: Witoon Prinyawiwatkul **Rank:** Professor **Student?** No
School of Nutrition and Food Sciences Ph: 8-5188
E-mail: wprinyawiwatkul@agcenter.lsu.edu **and** wprinya@lsu.edu

2) Co-Investigator(s): please include department, rank, phone and e-mail for each NONE
- If student as principal or co-investigator(s), please identify and name supervising professor in this space

3) Project Title: Consumer Acceptance and Perception of New and Healthier Food Products
4) Grant Proposal?(yes or no) NO **If Yes, Proposal Number and funding Agency**______
Also, if Yes, either: **this application completely matches the scope of work in the grant Y/N**__
OR
more IRB applications will be filed later Y/N___
5) Subject pool (e.g. Nutrition Students) **LSU Faculty, Staff, Students and off-campus consumers**
- Circle any **"vulnerable populations" to be used:** (children<18, the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted. **NONE**

6) PI signature________ ****Date** 3-12-2015 (no per signatures)
****I certify that my responses are accurate and complete.** If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU AgCenter institutions in which the study is conducted. I also understand that it is my responsibility to maintain copies of all consent forms at the LSU AgCenter for three years after completion of the study. If I leave the LSU AgCenter before that time the consent forms should be preserved in the Departmental Office.

Committee Action: Exempted ✓ Not Exempted___ **IRB#** HE15-9
Reviewer Michael Keenan **Signature** Michael Keenan **Date** 3-16-2015

Appendix B: JAR Data Analysis Example

Table 4.4 Saltiness perception based on the JAR responses as indicated by color vs. Taste.

Trt. Id.	Mode	Frequency (%)[ɤ]			CMH	Stuart-Maxwell	McNemar		
		Too Weak	Just About Right	Too Strong			TW	JAR	TS
1	Color	16.67	75.56*	7.78	**0.041**	**0.013**	0.157	**0.023**	0.540
	Taste	28.89	57.78*	13.33					
2	Color	8.89	77.78	13.33	0.191	0.166	0.293	0.305	1.00
	Taste	17.78	67.78	14.44					
3	Color	8.89	83.33	7.78	0.075	0.070	0.566	0.112	0.346
	Taste	15.56	68.89	15.56					
4	Color	13.33	73.33	13.33	0.818	0.803	0.909	0.944	0.975
	Taste	16.67	70.00	13.33					
5	Color	11.11	82.22	6.67	0.056	0.053	0.185	0.083	0.725
	Taste	22.22	66.67	11.11					
6	Color	25.56	64.44	10.00	0.650	0.600	0.759	0.719	1.00
	Taste	31.11	57.78	11.11					
7	Color	11.11	75.56	13.33	0.060	0.072	0.115	0.220	0.972
	Taste	24.44	62.22	13.33					
8	Color	10.00*	81.11*	8.89	**<0.001**	**<0.001**	**0.002**	**0.004**	0.725
	Taste	31.11*	57.78*	11.11					

[ɤ] Panelists' responses expressed as percent frequency per JAR-scale category: too weak (TW), just about right (JAR), and too strong (TS). **Bold** font indicates statistical significance (α=0.05). [ʊ] Cochran Mantel Hansel (CMH) and ^Stuart Maxwell tests. *Asterix indicates significant difference (P<0.05) based on McNemar test evaluating JAR category responses (column) between modes of perception (Color vs. Taste).

McNemar tests is usually used to compare two products and exactly two response categories by collapsing or combining the 3-point scale into two category responses at the time (e.g. "Just About Right" vs. "Not Just About Right"). Consider McNemar results for Treatment 1, for example, the p-value under TW column (0.157) corresponds to the difference between the Color and Taste mode of responses by comparing Too Weak vs. the not-too weak JAR category responses and successively for JAR and TS (0.023 and 0.54, respectively), Just About Right vs. not-just about right and Too Strong vs. not-too strong, respectively. The interpretation of these results, altogether, indicate that the physiological taste perception was less ideal per the decrease

Just About Right category responses (75.56 vs. 57.78). Whereas in the case of Treatment 8, moreover, the interpretation of the results suggests both a decrease Just About Right (81.11 vs. 57.78) and an increase in the Too Weak category responses (10.0 vs. 31.11). Thus Treatment 1 and 8 showed incongruence between the modes of responses, Color vs. Taste. In contrast, Treatments 2 to 7 showed no evidence of divergence or incongruence between the modes of responses, Color vs. Taste. This is an adequate follow-up analysis to gain further insight from JAR data in addition to that of CMH and Stuart-Maxwell methods (Rothman & Parker, 2009). In this study, McNemar test is used to compare two sets of responses of the same sample, Before vs. After, in stead of comparing two samples, thus allowing to determine differences in the responses between the modes of responses per treatment per category.

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Vita

Jose Ramon Alonso-Marenco was born in Guatemala, September 10th 1987. He earned the degree of Bachelor of Science in Food Science and Technology on December 5th 2009 from the Escuela Agricola Panamericana, Zamorano University, at the Valle del Yeguare, Honduras. Afterwards, he worked as an assistant farm manager and later as a service workshop supervisor. During this time, he pursued studying a Master degree in Food Science and Technology and a Master degree in Business Administration that were later discontinued after being offered an internship at Louisiana State University in May 2013. The internship took place at the Nematology Laboratory, under the supervision of Dr. Charles Overstreet, and eventually led to the opportunity to pursue a Doctorate degree at the School of Nutrition and Food Sciences under the mentorship of Dr. Witoon Prinyawiwatkul. His work as a Ph.D. student focused on multisensory perception, cognitive processes, and its applicability on the development and promotion of alternative versions of food products with lesser content of sodium. His path has and will continue to be driven by a desire to better himself, as a person and as a professional.