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Influences of Spiciness and Visual Color Cue On Salty Taste Intensity Perception In Reduced-Sodium Cheese Dips

Valentina Rosasco Silva
Louisiana State University and Agricultural and Mechanical College, vrosas2@lsu.edu

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INFLUENCES OF SPICINESS AND VISUAL COLOR CUE ON SALTY TASTE INTENSITY PERCEPTION IN REDUCED-SODIUM CHEESE DIPS

A Thesis

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ABSTRACT

The current high levels of dietary sodium intake are negatively affecting consumers' health. Reducing sodium consumption to the recommended amount could help prevent around 2.5 million deaths yearly and save up to $18 billion dollars in health care costs worldwide. The main objective of this research was to evaluate the possibility of increasing the saltiness perception and acceptability of reduced-sodium cheese dips by using the multisensory approach and analyzing gender differences towards salty taste expectations. Two experiments were conducted: I) The combined effects of gender and visual color cue on salty taste expectations, liking, and purchase intent (PI) of cheese dips; ii) Influences of spiciness and visual color cue on salty taste intensity perception in reduced-sodium cheese dips. Results in study I showed that increasing yellow/orange color intensity increased the expected saltiness intensity, switching the JAR rating from "too weak" to "too strong." Also, color intensity, particularly pale and most intense colors decreased the expected salty taste liking scores. Overall, females expected cheese dips with more intense yellow/orange color to be saltier than males, and they were more willing to purchase samples with less intense yellow/orange dips. Results from study II showed that expectancy disconfirmation driven by color intensity caused an assimilation/contrast effect in the perceived intensity of the salty taste. Generally, increasing color intensity from pale to medium, increased the perceived saltiness intensity. However, when a high discrepancy between expectations and actual taste was experienced at the most intense color, the perceived intensity decreased at all spiciness levels. Large mean-drops of the overall liking score were associated with a high discrepancy between expected vs. perceived salty taste. On the other hand, spiciness level was shown to influence saltiness

intensity perception [the spicier, the saltier]. Overall, by combining color intensity and spiciness level, the salty taste intensity perception of a reduced-sodium cheese dip was optimized to an ideal level and the PI increased by 54.4%. Findings from this research may help the food industry improve sensory characteristics and acceptability of reduced-sodium products, and thus achieve the current dietary goals of sodium consumption.

CHAPTER 1. INTRODUCTION

Eating is a multisensory experience that involves sensory integration and cognition (Verhagen & Engelen, 2006). Each sense has its own pathway to transform sensory inputs into meaningful information. However, senses commonly operate together, as signals from the environment can stimulate multiple sensory systems (Yeomans, Chambers, Blumenthal, & Blake, 2008). For instance, sensory visual cues, such as color, can strongly affect perception of flavor and taste. Visual cues play a key role in eliciting consumers' expectations. Understanding what consumers expect from a product is crucial for product developers, as meeting consumers' expectations will likely enhance product liking and purchase intent (Yeomans et al., 2008). Color is the single most important intrinsic sensory cue in eliciting expectations about food products (Spence, 2015a). In fact, it has been widely demonstrated that changing the hue or intensity of colors in foods or drinks influences flavor identification and taste intensity perception (Spence, 2015b).

Research regarding the influence of color on taste perception has suggested that it is possible to reduce food additives in products by increasing color intensity of foods (Spence, 2015a). Incorporating color in foods and drinks has been previously found to strongly enhance sweet and sour tastes (Spence et al., 2015; Spence, 2015a; Spence & Parise, 2012; Spence, Levitan, Shankar, & Zampini, 2010; Lavin & Lawless, 1998; Johnson & Clydesdale, 1982; Maga, 1974; Pangborn & Hansen, 1963; Pangborn,1960). However, there is very limited and contradictory research regarding the influence of color on salty taste perception. Most studies on color and salty taste have not evaluated expectations elicited by color. However, identifying salty taste expectations elicited by

visual color cues is crucial, as it has been demonstrated that expectancy disconfirmation can influence salty taste perception and product acceptance (Yeomans et al., 2008).

Additionally, the trigeminal sense has also been found to affect taste perception and hedonic responses to foods (Spence, 2015b). Recent studies have suggested that spicy compounds, particularly capsaicin, may increase saltiness perception and acceptability of products (Andersen, Byrne, Bredie, & Møller, 2017; Li et al., 2017; Narukawa, Sasaki, & Watanabe, 2011). Research on the multimodal-perception of taste provides a basis for exploring the possibility of using the combination of color intensity and spicy compounds as a strategy to reduce sodium in products. However, these effects have not been evaluated with real food applications. Cheese dips, which currently contain alarming amounts of sodium of 654 mg/serving (64g), on average, can be found in a variety of yellow/orange color intensities and spiciness levels. Therefore, cheese dips are a good food model to evaluate the combined effects of spiciness and color intensity on salty taste perception and product acceptability.

1.1. Objectives

The primary purpose of this research was to evaluate the viability of enhancing the saltiness perception and acceptability of reduced-sodium cheese dips by using the multisensory approach. Specifically, the objectives were:

   a. To assess whether color (yellow/orange) intensity of cheese dips affected salty taste expectations, liking, and purchase intent (PI) of female (FM) vs. male (MM) consumers.

b. To evaluate the combined effects of color (yellow/orange) and spiciness (cayenne) intensity on saltiness, liking, and PI of reduced-sodium cheese dips.

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CHAPTER 2. LITERATURE REVIEW

2.1. Sodium consumption

Sodium is an essential nutrient that helps in controlling the body's fluid balance, transmitting nerve impulses, and in muscle function (American Heart Association (AHA), 2017). However, high sodium intake is a major public health concern as it can lead to an increased risk of stroke and cardiovascular disease (Dijksterhuis, Boucon, & Le Berre, 2014). According to the World Health Organization (WHO), people consume an average of 9-12 grams of salt per day, which is almost twice as much as the recommended intake of 5-6 grams (WHO, 2016). In 2015, the Dietary Guidelines for Americans (DGA) indicated that sodium intake should be limited to 2,300 mg/d for the general population, and 1,500 mg/d for at-risk subgroups including people with hypertension, diabetes, chronic kidney disease, African Americans, and older adults (WHO, 2016; Institute of Medicine (IOM), 2010; CDC, 2018). Moreover, the American Heart Association (AHA) suggested that blood pressure and heart health can be improved if daily sodium intake is reduced by 1,000 mg (AHA, 2017), which could help prevent around 2.5 million deaths yearly (WHO, 2016).

According to the Institute of Medicine (IOM), over 75% of all sodium intake is associated with processed foods sold in stores or used as ingredients by restaurants (IOM, 2010). Sodium chloride (NaCl), commonly known as table salt, is the primary source of sodium in the diet. However, other sources of sodium such as monosodium glutamate, sodium bicarbonate, disodium phosphate, and sodium nitrate, among many

others, are used by the food industry to enhance the physical properties, taste, and palatability of products (IOM, 2010).

Even though sodium plays a critical role in the functionality of many food products, there is an active interest to reduce its consumption (Dijksterhuis et al., 2014). Organizations such as the IOM, WHO, WASH (World Action on Salt & Health), NSRI (National Salt Reduction Initiative), and CDC (Center for Disease Control and Prevention), among others, are currently working on reducing daily sodium consumption and are also encouraging companies to develop more reduced-sodium products. In fact, by 2025, the WHO is seeking to reduce the global population's intake of salt by 30% (WHO, 2016). Meeting this dietary consumption goal remains a challenge but reducing sodium intake to this recommended level could contribute to a reduction of up to 11 million cases of hypertension and save up to $18 billion dollars in health care costs worldwide (Polar & Sturm, 2009). Therefore, there is an undeniable need to generate more strategies that will help the food industry reduce sodium content without affecting the product's properties and acceptability.

2.2. Strategies to reduce sodium in products

The sodium reduction process includes the development of strategies that will compensate for the lack of salty taste, flavor, or changes in the physical properties of products. Several approaches such as the use of salt replacers (Feltrin, Souza, Saraiva, Nunes, & Pinheiro, 2015; Kloss, Meyer, Graeve, & Vetter, 2015; Wu et al., 2015; Guàrdia, Guerrero, Gelabert, Gou, & Arnau, 2008; Katsiari, Voutsinas, Alichanidis, & Roussis, 1997), salt enhancers (Kloss et al., 2015), particle size reduction (Rodrigues, de Souza, Mendes, Nunes, & Pinheiro, 2016), modification of the food structure (Torrico, Carabante,

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Pujols, Chareonthaikij & Prinyawiwatkul, 2015), and the multi-sensory approach (Chokumnoyporn, Sriwattana, & Prinyawiwatkul, 2016; Torrico et al., 2015; Dijksterhuis et al., 2014; Dötsch et al., 2009; Kremer, Mojet, & Shimojo, 2009) are good examples of proposed strategies that aim to overcome undesired characteristics of reduced-sodium products.

A common method applied in the food industry is the use of potassium chloride (KCl), a salt substitute that provides similar functionality as sodium chloride (Kloss et al., 2015). However, KCl is known to have an undesired bitter and metallic aftertaste (Torrico et al., 2015; Hooge & Chambers, 2010). Similarly, other chloride salt replacers such as $MgCl_2$ and $CaCl_2$ also impart off-tastes and can negatively affect some manufacturing steps of processing (Aliño, Grau, Toldrá, & Barat, 2010). One approach to enhance the acceptability of salt substitutes is by using bitterness blockers and sweeteners that can minimize the perception of bitter taste and off-flavors (Kloss et al., 2015). Another common strategy to enhance saltiness perception involves the modification of the physical form of salt. Reducing the crystal size of NaCl particles has been shown to increase its delivery rate to the tongue (Rama et al., 2013) and thus increase saltiness perception (Rodrigues et al., 2016; Moncada et al., 2015; Torrico et al., 2015; Rama et al., 2013). However, the increasing demand for less processed and refined products may limit the use of the particle size modification strategy.

Other less conventional approaches such the use of flavors, aromas, spicy compounds, and visual cues, use the multi-sensory perception principle to increase salty taste in products (Li et al., 2017; Chokumnoyporn et al., 2016; Narukawa et al., 2011; Kremer et al., 2009). For example, increasing flavor intensity of an aroma-related attribute

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intensified the saltiness perception of a reduced-sodium beef bouillon (Dötsch et al., 2009). Similarly, Chokumnoyporn et al. (2016) reduced the salt content of roasted peanuts by using soy sauce as an odor-induced saltiness enhancement method. On the other hand, expectations elicited by visual cues, such as the product's color, label, and packaging, have also been found to influence how consumers perceive salty taste. However, there is limited and contradictory research on salty taste perception as influenced by color. Lastly, recent studies have suggested that capsaicin may enhance saltiness perception, since consumption of spicy products has been found to activate similar areas of the brain as salty foods (Li et al., 2017). To date, no studies have investigated the combined effects of color and spiciness on saltiness perception. Therefore, exploring how color and spiciness interact with salty taste may result in a new sodium-reduction strategy that can easily be applied by the food industry.

2.3. Taste perception and the brain

Identifying factors affecting saltiness perception at the cognitive level may help in the development of new strategies to reduce sodium in products. Knowing how the senses and brain operate is critical to understanding the basics of perception and how color and spiciness may contribute to enhancing saltiness and acceptability.

2.3.1 The psychophysical mechanism of taste

The sense of gustation involves the detection of chemicals that trigger five basic tastes: sweet, sour, bitter, salty, and umami (Slocombe, Carmichael, & Simner, 2016). Taste buds, which are located between the fungiform papillae, contain between 50-100 taste receptors that activate when contacted by specific chemical molecules (Verhagen

Kadohisa, & Rolls, 2004). Taste receptors, also known as epithelial cells, receive information about the type and amount of taste when chemicals found in foods pass through the taste pore and bind to the gustatory cells (Lindemann, 2001). The sensory input is then transformed into electrical signals that are sent to the brain stem where the process of taste begins (Breslin, 2013).

Even though gustatory cells activate in the presence of a tastant, each basic taste is perceived through different channels. Salty taste is mainly elicited by positively charged Na^+ ions mediated by the ENaC (epithelial sodium channel) (Lindemann, 2001). The ENaC is the most commonly known pathway by which sodium enters to the taste cell and triggers an action potential (Lindemann, 2001). Once action potentials are activated, the taste message is sent by neurotransmitters to the taste area of the somatosensory/frontal cortex (Breslin, 2013). A secondary pathway for salty taste is believed to detect other ionic salts such as KCl and register saltiness intensity. However, this second pathway has not yet been clearly identified by researchers (Kuhn, 2016).

The central nervous system plays a key role in how taste and other senses are perceived. The network of nerve cells and fibers act as a control center that carry and transmit signals from the senses to different parts of the brain. Taste information is delivered via the cranial nerves, VII (Facial), IX (Glossopharyngeal), and X (Vagus), to the first gustatory area of the brain stem (Breslin, 2013; Verhagen et al., 2004). Gustatory fibers from the brain stem connect to the thalamus where signals are projected to the gustatory cortex, amygdala, hippocampus, and hypothalamus (Veldhuizen, 2011). Each area of the brain that receives sensory information plays an important role in perception and consciousness of taste.

The anterior insula and frontal operculum (AIFO), also known as the primary gustatory cortex, is where information is gathered, and sensation of taste is perceived (Veldhuizen, 2011). The secondary gustatory area, known as the orbifrontal cortex, is involved in behaviors that rely on reward-evaluation such as the judgement of liking (Yokum & Stice, 2011). Moreover, structures of the limbic system like the amygdala and hypothalamus, contribute to the emotional quality of taste, and the hippocampus facilitates the learning and memory of taste (Kuhn, 2016). After sensory inputs have been sent to each area, the brain organizes and integrates the information to make a subjective interpretation of the physical stimulus.

2.4.   Sensory perception

Sensory perception is the result of a combination of physical, physiological, and psychological processes (Schifferstein, 1996). As previously discussed, the brain can transform sensory inputs into sensations through a psychophysical process (Schifferstein, 1996). Yet, as signals are directed to the limbic system, the physical stimulus is subjectively decoded, and the psychological interpretation is stored in the hippocampus where memory of taste is controlled. The interpretation of a stimuli can be affected by top-down processes, theory-driven procedures that use previous knowledge to influence perception. Whenever consumers interact with a food product, the brain integrates information from previous experiences with new sensory inputs that are received prior to consumption. As a result, context, stimuli, and knowledge can generate powerful expectations that can affect the eating experience (Small, 2012).

2.5. The role of expectancy on taste and flavor perception

Expectations are anticipated product characteristics elicited by cues that trigger memories, emotions, learning, and cognition (Cardello, 1994). The high influence of expectations over food choice, perception, and liking might be explained by the fact that in nature, many foods contain toxic chemicals that can potentially harm the body (Piqueras-Fiszman & Spence, 2015; Veldhuizen et al., 2011). Therefore, expecting a product to perform in a specific way is not only a self-defense mechanism to keep the body safe but can also help consumers anticipate the level of benefit or reward that a product may give. Consequently, expectations are critical to purchase intent since meeting what consumers expect from a product will result in a repeated purchase (Cardello,1994). Moreover, if consumers expectations are not met, the sensory experience may decrease depending on the level of disconfirmation between expectations and actual taste/flavor (Yeomans et al., 2008).

Liking and perception of a sensory attribute can be affected by disconfirmed expectations positively or negatively. To date, four psychological models have been proposed to identify the effect of sensory incongruence on perception and hedonic appraisal: assimilation, contrast, generalized negativity, and assimilation/contrast. Assimilation effects, also known as cognitive dissonance, occur when consumers adapt their perception to their expected experience (Piqueras-Fiszman & Spence, 2015; Cardello & Sawyer, 1992). Assimilation effects were reported by Stolzenbach et al. (2013) when hedonic evaluation of apple juices increased due to high expectations elicited by product descriptors (Stolzenbach, Bredie, Christensen, & Byrne, 2013). Similarly, when a tomato soup was labeled as being "lean" or "healthy", consumers were expecting to

taste a soup with lower fat content than commercial brands, resulting in lower pleasantness and creaminess ratings (Yeomans, Lartamo, Procter, Lee, & Gray, 2001).

The second psychological model of disconfirmed expectations, contrast effects, occurs when consumers magnify the difference between expectations and actual perception, i.e., rating a product to be less sweet than what it is due to high sweetness intensity expectations. Contrast effects have been rarely reported and usually have a negative effect on liking ratings (Yeomans et al., 2008; Zellner, Strickhouser, & Tornow, 2004). Yeomans et al. (2008) demonstrated that when a novel savory ice cream was labeled as "ice-cream" vs. "frozen savory mousse", consumers were expecting a stronger sweet taste and very low saltiness intensity from the product labeled as ice-cream. After tasting the savory ice-cream, consumers perceived significantly less saltiness and higher sweetness intensity in the product labeled as "ice-cream", resulting on a decrease in the hedonic rating.

Moreover, the third effect of expectancy incongruence states that regardless of whether the product underperforms or exceeds expectations, the product will be negatively rated as expectations were not met (Piqueras-Fiszman & Spence, 2015). Lastly, according to the assimilation/contrast model, if the incongruence between expectation and experience is small, consumers may perceive the product in the way they were expecting. However, when the discrepancy is too large, contrast will likely occur (Cardello & Sawyer, 1992). Assimilation/contrast effects were reported by Cardello and Sawyer (1992) for the bitter taste of a novel fruit beverage. Influenced by product descriptors, when expectations for bitter taste were slightly low, consumers perceived the

product as less bitter. However, when consumers were expecting the product to be too bitter, a contrast effect was observed.

As seen, expectations can strongly influence how products are perceived and liked. Therefore, it is important to identify key factors that affect what consumers expect from a food. Expectations are elicited by several sensory cues that trigger memories from previous experiences. Visual appearance, aromas, sounds, and even touching a food prior to consumption can help consumers identify how the product will perform. However, when foods are found packed in the supermarket, expectations are mainly evoked by visual cues. Visual signals have been found to be so powerful, that more than 200 studies over the past 80 years have demonstrated their effect on liking, perception, and willingness to purchase (Spence & Piqueras-Fiszman, 2014). This wide range of research on visual cues demonstrates how influential the sense of sight can be, which might be explained by how vision is perceived and integrated in the brain.

2.6. Effects of visual cues on sensory perception

2.6.1. Visual perception

Vision is believed to be the dominant sense (Spence & Piqueras-Fiszman, 2014), as perceiving visual information requires the use of nearly half of the cerebral cortex. The vision process starts when light enters the eyes through the cornea and hits the lens that focus and refract electromagnetic waves to the retina. The inner neural layer of the retina is comprised of millions of photoreceptors, ganglion cells, and bipolar neurons (Veldhuizen et al., 2011). Two types of photoreceptors, rods and cones, convert light waves into electrical signals. Cones, which are divided into green, blue, and red identify

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color hues and details from light. However, cones have a low sensitivity to light and only activate under bright conditions. Rods on the other hand, have a higher sensitivity to light but can only detect brightness (Waggoner, 2013). These photoreceptors are connected to the retina through neurons that generate action potentials. Two specialized nerve cells, the ganglion and bipolar neurons, facilitate the pathway of electrical signals from the retina to the brain. The bipolar cells act as a port connecting photoceptors to ganglion cells that establish the disc found in the optic nerve. Finally, electric signals are carried by the optic nerve into the visual area of the thalamus and visual cortex where perception occurs (Veldhuizen et al., 2011).

2.6.2. Sensory integration

Eating is a multisensory experience that involves sensory integration and cognition. Taste and vision each have their own pathway to transform sensory inputs into meaningful information. However, senses commonly operate concurrently, as signals from the environment stimulate more than one sensory system (Yeomans et al., 2008). Flavor, the combination of taste, smell, and trigeminal sensations, exemplifies how senses influence each other. When molecules from the air travel up the nose and go to receptor cells found in the nasal cavity, information is sent to the olfactory bulb and the smell cortex located in the insula and OFC (Schifferstein, 1996). The interaction between the gustatory system and olfaction may be attributed to the fact that bimodal taste-olfactory neurons have been found at the OFC (Schifferstein, 1996), giving flavor perception as a result. Similarly, Rolls and Baylis (1994) demonstrated that bimodal neurons that respond to both visual and gustatory stimuli have also been found in the

orbifrontal cortex, which may explain why visual appearance of a food has such a strong influence on taste/flavor perception.

2.7.   Influence of visual color cues on perception

Appearance is considered a major quality indicator (Burrows, 2009) of foods, as consumers tend to inspect products visually prior their consumption or purchase. According to Spence (2015a), color is the most important intrinsic sensory cue related to eliciting taste and flavor expectations of foods and drinks. The reason behind consumers' special awareness to color might be attributed to the fact that in nature, colors can indicate certain sensory characteristics, nutrient availability, and even presence of toxic or harmful compounds in foods. For example, green color in fruits often indicates the presence of a sour aversive taste related to an unripe stage of the fruit. Whereas red and bright colors, as in strawberries for example, are indicative of a full stage of maturity in which beneficial compounds such as sugars and antioxidants are present. Consumers tendency to avoid or prefer colors in certain products plays a decisive factor on consumption behavior. In fact, the psychological influence of food colors has been studied on a wide variety of product including beverages, noodles, vegetables, cheese, yogurt, cake, jams, jellies, chocolates, sherbets (Spence, 2015a), dipping sauces (Sukkwai, Chonpracha, Kijroongrojana, & Prinyawiwatkul, 2017), among many others.

Over the past 70 years, research has demonstrated that expectations evoked by color intensity and/or hue often influence the perceived identity and intensity of flavor/taste (Spence et al., 2010). Spence (2015a) reviewed over 70 studies from the past 50 years showing evidence that color can critically affect taste and flavor perception. This

strong impact of color on taste/flavor perception has been attributed to the brain's ability to integrate inputs from different sensory systems.

2.7.1. Crossmodal correspondences

One area of multisensory perception that has drawn increased attention over the past few years is the study of crossmodal correspondences (Spence, 2015b). Crossmodal correspondence is the tendency for a sensory feature to be associated or matched with a sensory attribute of another sense (Spence & Parise, 2012). In other words, when taste, aroma, and flavor are associated with unrelated sensory cues (Spence, 2015b), i.e., matching the smell of a lemon with a yellow color (Spence et al., 2015).

Color cues have been found to generate crossmodal bias in taste/flavor perception. After reviewing empirical evidence from the last three decades, Spence et al. (2015) summarized the most consistent associations between colors and taste found in research. Bitter taste is strongly associated with black colors and somehow linked with purple/violet, saltiness with white and blue, sourness with yellow and green, and sweetness with pink or red (Spence et al., 2015). Research on crossmodal correspondences has proven that the tendency to match basic tastes with colors is not arbitrary. In most cases, associations between color and taste have been found to be consistent despite cultural differences and through time. Therefore, color-taste correspondences might be more "primitive" than other culturally related correspondences (Spence et al., 2015). Moreover, crossmodal effects on taste and flavor have also been found when varying the hue or intensity of a color.

2.7.2. Effects of color intensity on perception

Color is a visible expression of the electromagnetic spectrum that travels in waves with lengths between 380-750 nm. Light waves provide information about the dimensions of color: hue, saturation, and brightness. The frequency of a light wave determines its hue, while amplitude affects brightness. Greater amplitude indicates a greater amount of energy, and thus a brighter color (Waggoner, 2013). Color intensity is determined by the degree of saturation, which indicates the purity and amount of grey present in the color.

Generally, increasing intensity of a sensory input has been shown to increase neural firing regardless of the sensory system (Spence et al., 2010). Increasing the stimulus intensity of a sensory modality may lead to cross-modal correspondences with the intensity of a sensory input of another sense (Spence et al., 2015). Moreover, statistical regularity in the environment in which colored foods are more likely to be intensely flavored may contribute to generalized associations between color intensity and taste/flavor concentration (Spence et al., 2015; Spence et al., 2010).

Extensive research has shown that the addition of color to foods and beverages influences flavor and taste intensity perception. An early study performed by Maga (1974) demonstrated that adding food coloring to clear solutions increased or decreased consumers' ability to distinguish threshold levels for sweet, sour, and bitter taste. For example, sour and sweet tastes were detected at significantly lower and higher concentrations, respectively, when a green color was added to the solution. This study showed early evidence on how the addition of a color that is associated with a taste, can help consumers detect taste stimuli at lower concentrations. However, results across different studies have not always been consistent, and some researchers have failed to

demonstrate color-taste intensity interactions altogether. For example, Pangborn (1960) reported that a pear nectar was perceived as less sweet when a green color was added, which according to Maga (1974), could have been attributed to an association between green color and unripe pears that are commonly less sweet. However, when the experiment was replicated by Pangborn and Hansen (1963), green color was not found to significantly influence the perceived sweetness of the pear nectar.

Moreover, several studies have reported strong associations between color intensity and sweet taste. Lavin and Lawless (1998) showed that sweetness perception increased when panelists evaluated strawberry-flavored drinks with a dark red color and light green color compared to the light (red) and dark (green) versions. In another study, Johnson and Clydesdale (1982) demonstrated that sweetness intensity can be increased up to 10% by adding a red color to clear sucrose solutions. This study gave early evidence suggesting the possibility to reduce certain food additives, like sucrose, by increasing color intensity of foods (Spence, 2015a).

Even though the influence of color intensity on taste/flavor intensity perception has been somewhat inconsistent, there is a large amount of evidence that clearly demonstrates strong crossmodal color-taste interactions. Therefore, more research is needed in this area to support possible effects of color intensity on taste/flavor perception.

2.7.3. Color and salty taste

As previously stated, many studies have demonstrated how color influences flavor and taste perception. However, most studies have failed to demonstrate crossmodal effects between color intensity and salty taste. For example, Maga's threshold study did

not show any significant interaction between food coloring and salty taste sensitivity (Maga, 1974). Maga suggested that the reason behind the lack of association was caused by the fact that salty foods are found in many colors; pretzels (brown), potato chips (yellow), popcorn (white), olives (green, black), and pickles (green) (Maga, 1974). However, studies on crossmodal correspondences have supported that when people are asked to link colors with basic tastes, white and blue colors have been consistently associated with salty taste (Spence et al, 2015). In fact, one study performed by Harrar et al. (2011) demonstrated that when a sample of sweet popcorn was served in a blue bowl, salty taste intensity significantly increased by 4% (Harrar, Piqueras-Fiszman, & Spence, 2011).

Although there is evidence showing that people tend to associate salty taste with white and blue colors, very few studies have demonstrated associations between color with salty taste on real food applications. Studies performed on chicken broth have suggested that even though color intensity did not have a statistically significant effect on saltiness perception, trends observed in results suggest that color may influence the overall acceptability of salty foods (Gifford, Clydesdale, & Damon, 1987). For example, in a study performed by Gifford et al. (1987), no significant differences were found in flavor preference between an uncolored sample containing 0.80% (w/v) and a colored sample with 0.72% (w/v) of NaCl, which may indicate that there is an interrelationship between color, saltiness, and flavor.

It is important to consider that these few studies on color and salty taste perception are very limited in scope and have been mainly focused on unflavored solutions, chicken broth/bouillon, and more recently on mayonnaise-based dipping sauces. Additionally,

most studies have not investigated the influence of color intensity on consumers' saltiness expectations. Identifying salty taste expectations elicited by different color intensities is crucial, as it has been demonstrated that expectancy disconfirmation can influence salty taste perception (Yeomans et al., 2008). A study performed by Sukkwai et al. (2017), indicated that increasing the color intensity of a mayonnaise-based dipping sauce also increased the expected saltiness intensity of the product. However, after tasting the dipping sauce samples, the saltiness liking significantly decreased as color intensity increased. These unexpected results may have been caused by the inherent flavor of the colorant used in the sample (Sukkwai et al., 2017). These findings support the opinion of Gifford et al. (1987), who suggested that there is an interaction between color, flavor, and saltiness perception. Therefore, it is important to ensure that any residual flavor, aroma, or taste of colorants used in this type of study are imperceptible to consumers, as they may influence the salty taste perception. Another important aspect to consider is the fact that most studies in this area were performed over 30 years ago and with small sample sizes. Therefore, additional research, which uses different products, is needed to determine if an association between color intensity and saltiness perception exists using a larger sample size.

2.8.   The use of spicy compounds as a new approach for sodium reduction

2.8.1. Spiciness perception

As mentioned previously, the multimodal perception of taste is attributed to the fact that taste sensations co-occur with other sensory modalities (Breslin, 2013). Along with taste, sensations such as temperature, tactile textures, and pain can also be experienced when eating (Spence, 2015b). The somatic sensation of pain is detected by humans

through the transient receptor potential vanilloid 1 (TRPV1), a cation channel that carries information about noxious pain and heat to the brain. Trigeminal stimulants such as capsaicin (from peppers), piperine (from black pepper), and gingerol (from ginger), bind to the TRPV1 receptor causing sensations that are often described as painful, warm, and burning (Kapaun & Dando, 2017). Trigeminal nerve fibers of the TRPV1 are also sensitive to temperature, which is why chemical irritants can elicit a hot sensation in the mouth (Kapaun & Dando, 2017). The spicy sensation occurs when sodium and calcium ions flow into the cell through TRPV1 and activate neurons that respond to potentially damaging stimuli such as extreme temperatures and injury-related chemicals (Dubin & Patapoutian, 2010). When the sensory neurons are activated, an action potential gets triggered (Yang & Zheng, 2017) and a pungency sensation is experienced in the mouth.

Trigeminal inputs elicited by chemical irritants have been shown to contribute to flavor perception (Spence, 2015b). However, the effects of spicy compounds on taste perception, particularly the salty taste, has not been widely explored. In most cases, capsaicin has been shown to decrease intensity perception of sweetness, bitterness, and umami. Few studies to date have reported a suppression of sour and salty tastes.

2.8.2. Spicy compounds and saltiness perception

Saltiness perception was for a long time reported to be unaffected by the presence of capsaicin (Verhagen & Engelen, 2006). However, when Narukata et al. (2011) investigated the saltiness perception of NaCl solutions containing capsaicin, a significantly higher number of panelists indicated that solutions with capsaicin were saltier than the control without capsaicin. Moreover, a recent study by Li et al. (2017) demonstrated that spicy foods can influence saltiness perception and salt intake by

modification of the neural processing of salty taste signals. The study validated that capsaicin administration increased OFC responses to salty taste, an area of the brain that is responsible for the reward-evaluation and acceptance of foods. In addition, a higher preference for spiciness was associated with a higher sensitivity and a lower terminal threshold for salty taste (Li et al., 2017).

Findings from these studies suggest that exploring how spiciness affects saltiness perception may result in a new strategy to reduce sodium in products. However, more research is needed to determine if the use of spicy compounds can successfully enhance saltiness perception or increase acceptability in reduced-sodium products.

2.9. Market opportunity for spicy products

Consumer-driven product development requires Research and Development (R&D) scientists to acquire a detailed understanding of what consumers desire in a food product. Spicy products represent a great market opportunity for the food industry, as consumers are increasingly demanding new and hotter/spicier products. According to Kalsec®, food companies that are looking to innovate should consider development of hot and spicy foods. Every year, the Kalsec® HeatSync® Heat Index, which was developed by Kalsec® and Innova Market Insights, analyzes how many new products containing spicy ingredients are introduced to the market. In 2017, the heat index indicated that global spicy/hot food product introduction grew for a ninth straight year, increasing 6% compared to the previous year (Kalsec®, 2017).

Kalsec's report on consumer trends for 2017, which surveyed over 1,400 U.S consumers, showed that 9 out of 10 Americans enjoy eating spicy foods with some level

of heat. Also, the survey showed that 1 out of 4 consumers are eating spicy foods more often and prefer spicier products compared to the previous year. The report also indicated that millennials (18-34 years old when surveyed) are eating spicier foods and are more adventurous when choosing their hot/spicy ingredients. These findings suggest that the demand for spicy foods will be a long-term trend as younger generations are interested in more innovative and spicier products (Kalsec®, 2017).

The survey also showed that there is a preference for spicy foods with particular peppers. Findings showed that 36% of consumers indicated that the spiciness source is an important aspect for them. Jalapeño, cayenne, and chipotle led the ranking of preferred peppers by consumers. After jalapeño, cayenne was shown to be the second most preferred pepper (Kalsec®, 2017).

Finally, the report also presented the top product categories in terms of fastest growth rate in the market. Cooking sauces, table sauces, bouillons/stocks, and savory/salty snacks were the top 4 leading categories in new product launches that contained spicy/hot ingredients. Also, savory spreads have been shown to be one of the top food application sub-categories as it exhibited one of the strongest growth rates. Over the past 10 years, the spicy/hot savory spreads product launches grew at a rate of 19%, making it a leading category. These data show that savory spreads would be a good category for exploring new spicy products as consumers are already expecting to experience some heat or spice (Kalsec®, 2017).

2.10. Suitability of cheese dips as a case study

Within the savory spreads category, cheese dips are one of the products containing the highest amount of sodium per serving in the market. Cheese dips, also known as pasteurized process cheese spreads, are often labeled as cheese sauce, salsa con queso, nacho cheese, queso, or cheese spread, among others. They can be found in supermarkets in the refrigerated section or, more commonly, in a shelf stable form.

Table 2.1. The amount of sodium per serving of cheese dips' leading shelf-stable brands

#	Brand	Grams of sodium/serving			
		2 Tbsp. (32g)	DV%	1/4 Cup (64g)	DV%
1	Velveeta Cheese Sauce	458.5	19.9	917	39.9
2	Cheez Whiz	409.6	17.8	819.2	35.6
3	Kraft Old English Spread	569.6	24.8	1139.2	49.5
4	Tostitos Medium Salsa Con Queso	263.5	11.5	527	22.9
5	Frito Lay Jalapeno Cheddar Flavored Cheese	220	9.6	440	19.1
6	Ragu Cheese Sauce	235	10.2	470	20.4
7	Fritos Flavored Cheese Dip	220	9.6	440	19.1
8	Great Value Melt 'n Dip Cheese	410	17.8	820	35.7
9	Ricos Gourmet Nacho Cheddar Cheese Sauce	270	11.7	540	23.5
10	On The Border Monterey Jack Queso	260	11.3	520	22.6
11	Herdez Queso Dip	290	12.6	580	25.2
12	Taco Bell Salsa Con Queso	436	19.0	872	37.9
13	Pace Salsa Con Queso Dip	270	11.7	540	23.5
14	Puck Pure and Natural Cheese Cream Spread	331	14.4	662	28.8
15	Great Value Salsa Con Queso Cheese Dip	263.5	11.5	527	22.9
Average		327.1	14.2	654.2	28.4

Cheese dips can also be found in restaurants as a side or appetizer, gas stations, and concession stands of movie theaters, games, and events. The Code of Federal Regulations' (CFR) recommended serving size for dairy-based dips is two tablespoons (30 mL) (CFR, 2017). However, several companies label their cheese dips with a recommended serving size of ¼ cup (4 Tbsp), as it represents a more realistic serving. Fast food restaurant servings sizes range from 1oz. to 8 oz. and can contain over 800mg of sodium per serving, which accounts for 35% of the recommended daily value (DV). Casual-dining restaurants' cheese dip appetizers have been found to have alarming amounts of sodium: up to 4,250 mg per dish. Moreover, pasteurized process cheese spreads can contain up to 50% of the recommended DV of sodium per serving. On average, leading shelf-stable cheese dips contain 654mg of sodium per 64g (1/4 Cup) which accounts for 28% DV (Table 2.1).

2.10.1.   Sodium sources in cheese dips

Sodium in cheese dips can come from different ingredients that play important roles in the texture, body, flavor, and shelf life of the product (Cruz et al., 2011). Added sodium chloride, monosodium glutamate, and salted cheeses act as flavor enhancers and increase palatability (Cruz et al., 2011). Other additives, such as sodium alginate, sodium citrate, sodium phosphate, and sodium stearoyl lactylate, contribute to the characteristic spreadable and thick texture of the cheese dips. Emulsifying salts (ES) like sodium phosphate or sodium citrate play an essential role in the cheese dip manufacturing process.

Emulsifying salts are also responsible for giving the desired smooth, creamy, and homogeneous matrix that consumers expect to find in a cheese dip. In its solid form,

cheese is a stable mixture of fat, moisture, and micelles of agglomerated casein proteins that are held by calcium ions. However, when cheeses are heated, their fats begin to melt. This disrupts most of the bonds holding casein molecules together, which causes the protein matrix to collapse and the cheese itself to melt (McGee, 2017). Additionally, the heating process causes the casein net to shrink, which compresses fat globules and releases moisture entrapped within the network. As a result, the previously homogeneous and stable solid cheese takes on a new gummy and pudding-like texture with free water and oil (Fox et al., 2000). ES can prevent the undesired textural properties of heated cheeses by facilitating ion exchange, increasing pH, and contributing to protein hydration. Increasing the pH of cheese causes its casein proteins to adopt negative charges and repel each other. Also, ES sequesters calcium ions from the micelle and replaces them with sodium ions. This process allows proteins to become hydrated and dispersed within the matrix. Once dispersed, proteins act as emulsifying agents, which prevent moisture and fat separation. The end result is a desirable smooth texture (Cruz et al., 2011; El-Bakry, Duggan, O'Riordan, & O'Sullivan, 2010).

Emulsifying salts are essential for the textural properties of processed cheeses and can be used in spreads in levels no higher than 3% (w/w) of the finished product (Cruz et al., 2011; Fox et al., 2000). ES contribute significantly to the sodium content of cheese dips. However, salty taste in processed cheeses is mainly associated with added NaCl and the use of salted cheeses, which accounts for over 60% of the sodium content (El-Bakry et al., 2010). Salty taste has been found to be a primary driver of liking in cheese sauces (Childs, Yates & Drake, 2009). Reducing a significant amount of sodium from cheese dips will likely decrease its overall acceptance. Using the multisensory approach

as a sodium reduction strategy in cheese dips has not yet been reported. Increasing color intensity and spiciness level will be suitable for this food application as consumers are already familiar with different color intensities and heat levels in this type of products.

2.10.2.   Color of cheese dips

Cheese dips can come in many yellow/orange color intensities or in a white shade. The natural yellowish color of bovine cheeses comes from carotenoids found in grass and clover (Fox et al., 2000). Animals cannot synthesize carotenoids, but cows can absorb and transfer them from plant materials to their tissue and milk. The natural color of a cheese is dependent on the animal's diet. However, most current cattle diets for large scale production are very limited in pasture, which results in dairy products with a white color. Color in cheeses is a critical attribute towards the purchase intent, as people relate the yellow/orange color with the flavor intensity and fat content of the product (Wadhwani & McMahon, 2012). Therefore, to maintain uniformity and enhance a product's appeal, butter and cheeses are often colored to a yellow/orange hue (Wadhwani & McMahon, 2012). Annatto extract obtained from achiote seeds (*Bixa Orellana)* is the main natural colorant used in the U.S dairy industry (Wadhwani & McMahon, 2012; Fox, 2000). Annatto's characteristic color comes from its two main carotenoid pigments, bixin and norbixin, which can be made fat soluble for application in butter, or water soluble for cheeses.

2.11. Literature review overview and conclusion

The current high levels of sodium consumption have a negative impact on consumers' health. In response, the food industry and many health-related organizations

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are seeking to reduce dietary sodium intake and develop more low sodium products. However, reducing sodium from products is incredibly challenging, as salt plays an essential role in the functionality, safety, and acceptability of food products. Therefore, there is a need to develop new strategies that will enhance saltiness perception and acceptability of reduced-sodium products.

Several techniques from the multisensory approach, such as the use of flavors, aromas, and visual cues, have been used in attempts to increase salty taste perception. Particularly, color and spicy compounds have been found to influence flavor and taste. Yet, no studies have investigated the combined effects of color and spiciness intensity on saltiness perception. Current market growth and demand for products containing spicy ingredients suggest that the use of spice would be a feasible strategy to apply in the food industry. However, more research is needed to understand if the use of spicy compounds can increase saltiness perception when used in real food products.

The projected market growth, consumer familiarity with different color and spiciness intensities, and the alarming amounts of sodium in cheese dips, make cheese dip an ideal food application to test if an association between salty taste, color, and spiciness does indeed exist. Findings from this research may help the food industry reduce sodium from products without affecting their acceptance and future repurchase. In general, research on how to improve sensory characteristics of reduced-sodium products plays a key role in meeting the current dietary goals of sodium consumption.

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CHAPTER 3. COMBINED EFFECTS OF GENDER AND VISUAL COLOR CUE ON SALTY TASTE EXPECTATIONS, LIKING, AND PURCHASE INTENT OF CHEESE DIPS.

3.1. Introduction

Sensory visual cues, such as color, influence consumers' expectations of flavor (aroma/taste), hence product liking and purchase intent (PI). Understanding what consumers expect from a product is crucial for product developers as meeting consumers' expectations will likely enhance the eating experience (Yeomans et al., 2008). Color is the single most important intrinsic sensory cue in eliciting expectations about food products (Spence, 2015a). In fact, it has been widely demonstrated that changing the hue or intensity of colors in foods or drinks influences flavor identification and taste intensity perception (Spence, 2015b).

Crossmodal interaction between the sensory modalities of taste and vision has been extensively proven for sweet and sour tastes (Spence et al., 2015). However, limited research has been conducted on crossmodal interaction between color and salty taste. Studies on broths and colored solutions have failed to find significant effects of color on saltiness perception. Maga (1974) attributed this to the fact that salty foods can be found in many colors. However, we hypothesized that evaluating consumers' salty taste expectations as influenced by color intensity may be a key factor in understanding salty taste-color interactions. Psychological effects driven by expectancy disconfirmation can increase or decrease intensity perception of taste (Yeomans et al., 2008). Finding the right level of incongruence between salty taste expectations and actual taste may lead to positive assimilation effects, and therefore an increase in saltiness perception.

On the other hand, expectations elicited by visual color cues are dependent on consumers' cognition, genetics, and several environmental variables that can be experienced prior to consumption. For instance, particular colors induce specific flavor/taste expectations depending on consumers' knowledge, memory, and cultural beliefs (Spence et al., 2015). Most studies investigating the influence of color on saltiness perception have paid little attention to differences in expectations of certain demographics. However, studies have shown that the same food color can elicit different expectations in different groups of consumers (Spence, 2015a).

Currently, males consume almost twice the recommended daily intake of sodium, while women exceed recommended consumption by 1.3 times (USDA, 2008). The difference in sodium intake between genders might be due to the fact that women tend to be more sensitive to changes in sodium concentration and perceive significantly more saltiness from high-sodium products than men (Hayes, Sullivan, & Duffy, 2010). Dissimilarities in sensitivity and preference to salty taste between genders suggests that females and males may also expect different saltiness intensities from the same color cue. However, differences in saltiness expectation as influenced by gender and color intensity have not yet been reported. Therefore, the objective of this study was to evaluate whether color (yellow/orange) intensity of cheese dips affected salty taste expectations, liking, and purchase intent (PI) of female (FM) vs. male (MM) consumers.

3.2. Materials and methods

3.2.1. Formulation

Five "cheese dips" with varying yellow/orange color intensities were developed for the study; pale (P), moderately pale (MP), medium (M), moderately intense (MI), and intense (I). Treatments were formulated with a mayonnaise base (Hellmann's® Mayonnaise, Unilever, Englewood Cliffs, NJ, USA) and different concentrations of a colorant mix to mimic the consistency and color of real cheese dips. The colorant mix included 40% Celestial Yellow (GNT-EXBERRY®, GNT USA, INC., Tarrytown, NY, USA), 40% Mango Yellow (GNT-EXBERRY®, GNT USA, INC., Tarrytown, NY, USA), and 20% of 03044 Orange dispersion (Sensient®, Sensient Technologies Corporation, Milwaukee, WI, USA). Color intensity range was developed based on a comparison between different commercially available shelf-stable cheese dips in the supermarket.

Table 3.1. Treatment identification of cheese dip samples with different color intensities used for the study

Treatment	Sample description	% of colorant used*
T1	Pale	0.40%
T2	Moderately pale	1.25%
T3	Medium	2.50%
T4	Moderately Intense	5.00%
T5	Intense	8.75%

3.2.1 Color measurement

Cheese dip color was measured in triplicate by reflectance using a benchtop spectrophotometer (model CM-5, Konica Minolta, Jakarta Raya, Indonesia). Calibration

with white and zero standards was performed before samples were analyzed. Color measurement was reported on L^* (lightness), a^* (+ for redness, - for greenness), and b^* (+ for yellowness, - for blueness) values. Also, to have a better color spectrum parameter and color saturation/intensity, the hue angle and chroma values were calculated according to HunterLab (2017). The hue angle was calculated as the inverse tangent of the ratio b*/a* and chroma as the square root of a*²+b*². Finally, ΔE was calculated, using the "pale" treatment as the reference, to measure the change in visual perception of the samples.
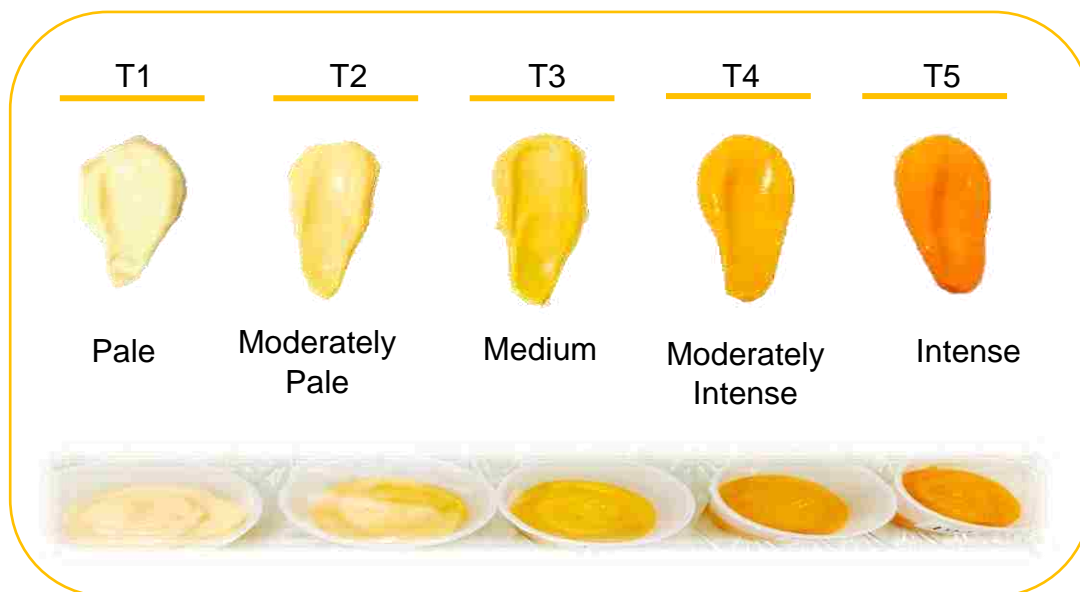
Figure 3.1. Actual treatment colors used for the study

3.2.2. Consumer test and participants

The sensory evaluation study protocol was approved by the Institutional Review Board of Louisiana State University (LSU) Agricultural center (IRB# HE15-9). A total of 240 participants were recruited from a pool of LSU students, faculty, and staff. All participants met the following criteria: (1) at least 18 years of age, (2) did not present any

visual impairment or color blindness, (3) Availability of 7-10 minutes to complete the survey. Consumers were required to read and sign a consent form (IRB # HE 15-9) before the study. The questionnaire was completed electronically using the Compusense® five software (Compusense® five, Release 5.6 with Compusense Inc., Guelph, Ontario) at the Sensory Science Laboratory of the School of Nutrition and Food Sciences, LSU, LA., U.S.A.

Without tasting the samples, 240 consumers (120 females and 120 males), visually evaluated all five cheese dip samples in a balanced design for direct comparison. Samples were randomly assigned to consumers and were evaluated in a room with individual sensory booths and natural fluorescent lights. Panelists were asked to evaluate the samples from left to right and each sample was labeled with a randomized 3-digit code created by Compusense® five to minimize psychological biases.

3.2.3. Evaluation of salty taste expectations, liking, and purchase intent

Based on visual observation, panelists evaluated their expected salty taste and cheese flavor liking, color liking, and overall-liking (OL) using a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely). Subsequently, a 3-point JAR (Just About Right) scale was used to measure the expected intensity of the attributes in relationship to the consumers' ideal intensity level. In this case, panelists evaluated their perceived color intensity and the expected intensity for the salty taste and cheese flavor (for color: 1=too pale, 2=JAR, 3=too Intense; for salty taste: 1=not salty enough, 2=JAR, 3=too salty; for cheese flavor: 1= not cheesy enough, 2=JAR, 3=too cheesy). For the purchase intent (PI) assessment, participants were asked to rank the products based on

their willingness to purchase the samples (1=definitely will not buy; 5=definitely will buy). A tie option was not available for the PI evaluation.

3.2.4. Data analysis

To evaluate if increasing color intensity significantly affected the liking scores of the tested attributes, a one-way ANOVA (a Glimmix procedure) followed by a Post-hoc Tukey's Standardized range test (α = 0.05) was performed. Also, a student's t-test was used to evaluate if the salty taste liking scores were significantly different between females and males. A MANOVA procedure was performed to test if the 5 cheese dip samples were different when all evaluated attributes were considered simultaneously. DDA (descriptive discriminant analysis) was used as a complement to MANOVA to determine which product attributes contributed to the product differences. JAR data were analyzed using a penalty analysis to investigate how the overall liking score of the products was affected when attributes were expected to be not ideal. PI data were analyzed using Christensen's et al. (2006) multiple comparison procedure of ranked data. Finally, data from color measurements were analyzed using a one-way ANOVA (a Glimmix procedure) followed by a Post-Hoc Tukey's Studentized range test (α = 0.05). Statistical analyses were performed using the SAS 9.3 software (Statistical Analysis System NC, USA).

3.3.   Results and discussion

3.3.1. Effects of color concentration on instrumental analysis and color liking

The effect of colorant concentration on color values of cheese dips is presented in Table 3.2. Addition of the colorant mix significantly changed all color parameters

evaluated by instrumental analysis. Increasing colorant concentration significantly (P>0.05) decreased L* values, while a* and b* values increased. A decrease in L* values indicates an increase in the darkness of the color, while increases in +a* and +b* scores correspond to color shades with higher degrees of redness and yellowness respectively. Consequently, the hue angle slightly decreased from 69.8° (T1) to 64.1° (T5). Considering that on the color wheel, a 0° indicates +a* (red) and 90° refers to +b* (yellow), samples with higher amounts of colorant presented a shade with slightly more red. The chroma value, an indicator for color intensity/saturation, drastically increased from 30.32 to 75.02 from the "pale" (T1) to the "intense" (T5) cheese dip treatments. These results indicate that increasing colorant concentration produced cheese dips with highly different yellow/orange color intensities (chroma) and minimally different color spectrums (hue angle). Also, all colors were theoretically different and perceptually distinguishable based on ΔE>2.3.

On the other hand, increasing yellow/orange color intensity (b* values from 28 to 67; chroma values from 30 to 75) significantly (P>0.05) affected consumers' (n=240) color liking scores (Figure 3.2.). Switching the cheese dips' color intensity from "pale" (chroma = 30) to "medium" (chroma = 55), significantly increased the color acceptability of the samples. However, treatments with the highest color intensities (chroma values from 66 to 75) elicited considerably lower color liking scores among the general population. Similar results have been previously observed in literature. Wadhwani and McMahon (2012), reported that changing the color shade of cheddar cheeses from "white" to

Table 3.2. Instrumental analysis of cheese dip samples with different color concentrations

Treatment	L*			a*			b*			Hue° [β]	Chroma[δ]	ΔE
T1	84.34	±	0.05	10.47	±	0.08	28.45	±	0.04	69.8	30.3	N/A
T2	78.8	±	0.02	17.26	±	0.21	41.54	±	0.06	67.4	45.0	15.8
T3	74.73	±	0.04	22.5	±	0.01	50.56	±	0.11	66	55.3	26.9
T4	69.67	±	0.07	28.15	±	0.05	59.86	±	0.04	64.8	66.2	38.9
T5	64.8	±	0.07	32.77	±	0.05	67.48	±	0.02	64.1	75.0	49.0

[m]Bolded and underlined variables were significantly different (P<0.05) among all samples based on ANOVA and Tukey's post-hoc test
[φ]Mean ± standard deviation from three independent replications
[β]Calculated as arctan(b*/a*); [δ] Calculated as $\sqrt{a*^2+b*^2}$

"orange", increased the color liking scores. However, cheeses with a high orange color intensity elicited lower color liking scores. Similarly, Sukkwai and others (2017) also observed a decrease in the color liking score of a mayonnaise-based dipping sauce containing a high orange colorant concentration (hue= 53.21, chroma = 44.6), compared to uncolored (hue= -89.6, chroma =10.14) and medium colored samples (hue= 56, chroma = 29.2).

Understanding consumers' acceptance towards the color of foods is essential. Research has demonstrated that the color of food products influences food-related behaviors such as purchase intent and food intake (de Wijk et al., 2004). Therefore, achieving a higher saltiness perception would be ineffective if the color shade/intensity that elicited the highest salty taste is considered unacceptable by consumers. A possible explanation regarding the decrease in color liking scores associated with the "moderately intense" and "intense" treatments may be related to an association between highly intense colors and the use of artificial colorants. Over the years, consumers have expressed general health-related concerns regarding the use of artificial food colorants. This has led to an increased demand for the use of more natural colors (Spence et al., 2015). In fact, Sukkwai et al. (2017) reported that increasing the color intensity of mayonnaise-based dipping sauces increased the score of the negative emotion term "worried" and decreased the color and overall liking scores. However, when panelists were shown a statement indicating that the colorant used in the dipping sauces came from a natural source, the score of the emotion term "unsafe" significantly decreased. Therefore, cheese dips with highly intense colors might have been perceived as less "natural" than less intense colors, resulting in a decrease in the color liking and overall liking scores (Table 3.2.). However,

this particular hypothesis was not investigated in this study and more research is needed

to understand why highly intense colors tend to decrease the color and overall liking

scores.

*Color liking

General (n=240)

T1: 3.95
T2: 5.66
T3: 6.73
T4: 4.93
T5: 3.24
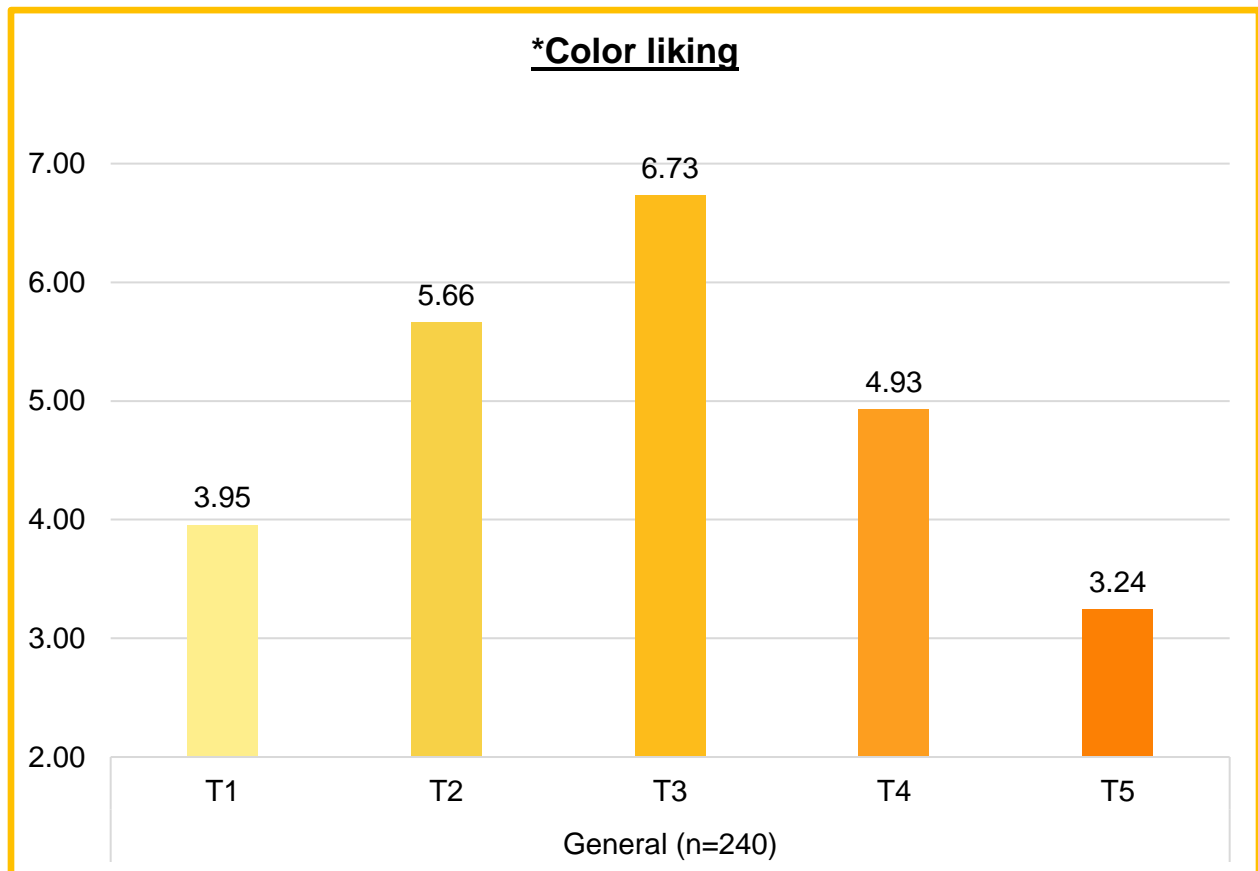
ᵞMeans scores based on a 9-point hedonic scale.
*Attribute was significantly different (P<0.05) among samples based on ANOVA and Tukey's test.

Figure 3.2. Color liking scoresᵞ elicited by cheese dips with different color intensities, based on visual cues

3.3.2. Influence of color intensity on the expected salty taste, cheesy flavor, and overall liking of cheese dips

Prior to product consumption, color plays an important role in modulating

consumers' expectations about taste and flavor intensity (Spence et al., 2010). These

expectations can later be confirmed or disconfirmed after product tasting, and thus affecting the overall eating experience (Verhage & Engelen, 2006). Moreover, just as consumers can experience a sensory expectancy disconfirmation, they can also perceive a hedonic disconfirmation of expectations (Spence et al., 2015), i.e., when consumers realize they do not like particular product characteristics. Therefore, expecting a product attribute to be liked better may contribute to enhancing overall acceptability of the product after consumption if an expectancy assimilation is observed.

Cheese dip samples with a "medium" color intensity elicited the highest liking scores of all attributes (Table 3.3. & Figure 3.3.). Color intensity, particularly "pale" (T1) and most "intense" (T4 and T5) colors, significantly (P<0.05) decreased overall liking, expected salty taste, and expected cheese flavor liking scores. As observed for the color liking attribute, increasing color intensity from "pale" to "medium" also resulted in an increase in the overall liking of the product, changing the score from a "dislike slightly" (4.31) to a "like moderately" (6.89) rating. However, increasing the color intensity from "medium" to "intense" decreased the overall liking score by 3.24 points. DuBose et al., (1980) reported similar results for the overall acceptability of flavorless "lemon" cakes with different yellow color intensities. Increasing the yellow colorant concentration from 0.0% to 0.003% significantly elicited higher overall acceptability of the cakes. Yet, when 0.006% and 0.009% of colorant was added to the cakes, the overall liking scores dropped (DuBose, Cardello, & Maller, 1980).

Table 3.3. Consumer acceptability scores[γ] elicited by cheese dips with different color intensities, based on visual cues

Attribute	GENERAL RESULTS (*N=240*)				
	1-Pale	2-Moderately pale	3-Medium	4- Moderately Intense	5-Intense
Color*	3.95 ± 2.26	5.66 ± 2.14	6.73 ± 1.57	4.93 ± 2.14	3.24 ± 2.08
Cheesy flavor*[β]	4.27 ± 2.28	5.74 ± 2.04	6.91 ± 1.56	5.18 ± 2.07	3.67 ± 2.17
Salty Taste*[β]	4.28 ± 2.15	5.63 ± 1.97	6.50 ± 1.58	5.00 ± 2.03	3.72 ± 2.14
Overall liking*	4.31 ± 2.30	5.80 ± 2.05	6.87 ± 1.64	5.10 ± 2.06	3.63 ± 2.08

[γ]Means and Standard Deviation based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).
[β] Expected attribute
*Attributes were significantly different (P<0.05) among samples based on ANOVA and Tukey's test.

γMean scores based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

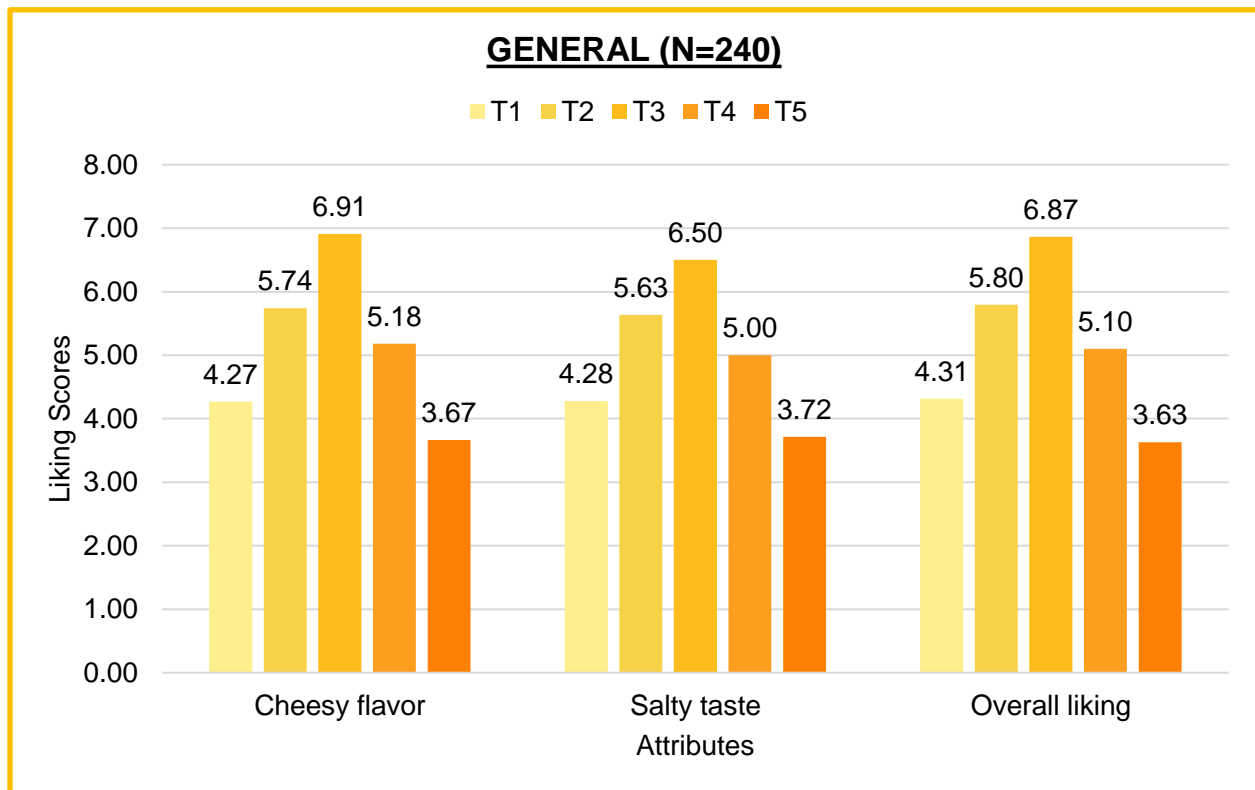Figure 3.3. Consumer acceptability scores[γ] elicited by cheese dips with different color intensities, based on visual cues

3.3.3. Combined effects of gender and visual color cues

Among adults, a higher percentage of males (98%) than females (80%) currently exceed the recommended daily allowance of sodium intake (CDC, 2016). Studies have shown that women tend to be more responsive to changes in sodium concentrations and perceive significantly more saltiness from high-sodium products than men (Hayes et al., 2010). According to Hayes et al. (2010), salty taste intensity perception is dependent on the taste function across individuals. This indicates that a stimulus that is perceived as weak in terms of saltiness might be perceived as strong by a different individual (Hayes et al., 2010). As mentioned, some studies have shown differences between males and females in saltiness perception and liking. Therefore, color cues might also be perceived differently across gender and elicit different salty taste expectations.

a) Influence of gender on the expected salty taste, cheesy flavor, and overall liking of cheese dips

Liking scores of all attributes for both females and males presented a similar trend as that observed in the general results. For both females and males, increasing color intensity from "pale" to 'medium" increased hedonic responses, while more intense colors elicited lower liking scores (Tables 3.4. & 3.5.). However, it was observed that males (Figure 3.4.) tend to give higher liking ratings, particularly for the more intense colors, compared to women.

Table 3.4. Liking scores$^\gamma$ of cheese dips with different color intensities of males, based on visual cues

Attributes	MALES (N=120)														
	1-Pale			2-Moderately pale			3-Medium			4- Moderately Intense			5-Intense		
Color	3.78^c	±	2.26	5.53^b	±	2.07	6.9^a	±	1.45	5.36^b	±	1.96	3.71^c	±	2.18
Cheesy	4.31^c	±	2.28	5.73^b	±	1.91	7.01^a	±	1.49	5.56^b	±	1.92	4.14^c	±	2.19
Salty Taste$^\beta$	4.38^c	±	2.15	5.54^b	±	1.92	6.52^a	±	1.53	5.42^b	±	1.96	4.41^c	±	2.19
Overall liking	4.29^c	±	2.34	5.83^b	±	1.91	7.13^a	±	1.40	5.43^b	±	2.02	4.12^c	±	2.12

$^\gamma$Means and Standard Deviation.
$^{a-e}$ Means with different superscripts within a row indicate significant differences ($P<0.05$) based on ANOVA and Tukey's. Values are based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).
$^\beta$ Expected attribute.

$^\gamma$Mean scores based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

Figure 3.4. Liking scores$^\gamma$ of cheese dips with different color intensities of males, based on visual cues
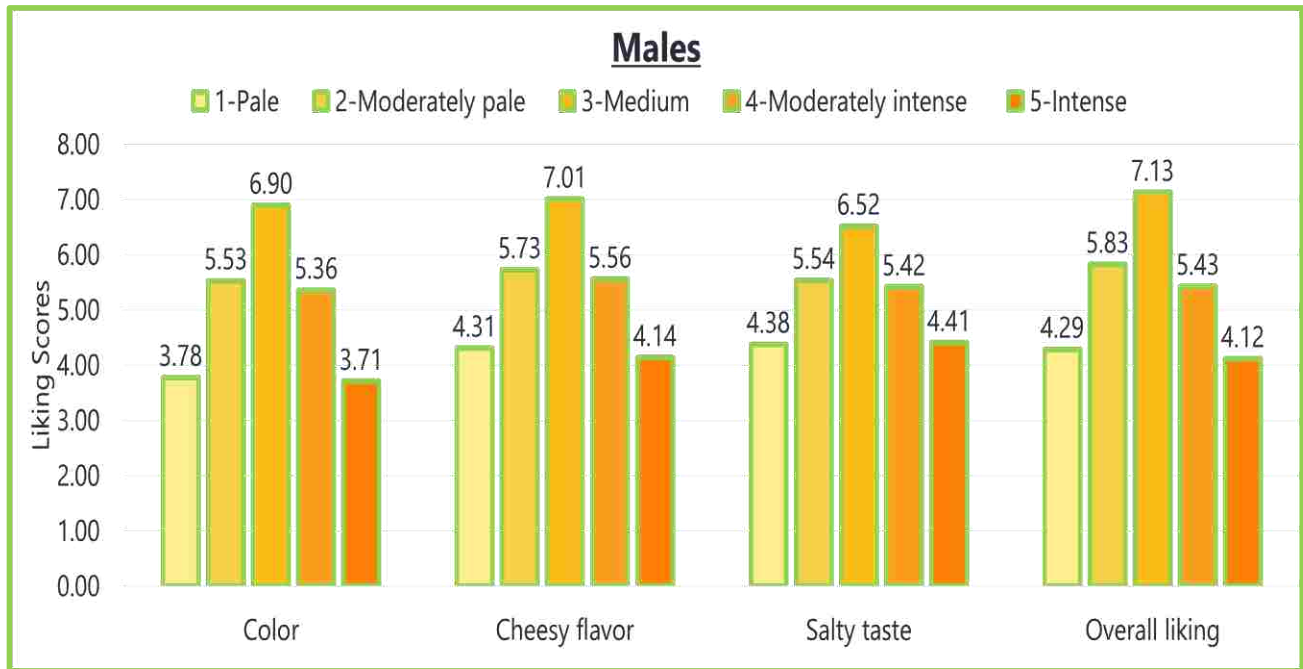
Table 3.5 –Liking scores$^\gamma$ of cheese dips with different color intensities of females, based on visual cues

Attributes	FEMALES (*N*=120)														
	1-Pale			2-Moderately pale			3-Medium			4- Moderately Intense			5-Intense		
Color	4.12[c]	±	2.26	5.78[b]	±	2.21	6.56[a]	±	1.68	4.49[c]	±	2.23	2.77[d]	±	1.86
Cheesy[β]	4.22[c]	±	2.29	5.75[b]	±	2.18	6.80[a]	±	1.63	4.8[c]	±	2.14	3.19[d]	±	2.05
Salty Taste[β]	4.17[c]	±	2.16	5.72[b]	±	2.02	6.47[a]	±	1.62	4.58[c]	±	2.02	3.03[d]	±	1.86
Overall liking	4.33[c]	±	2.28	5.76[b]	±	2.19	6.60[a]	±	1.82	4.77[c]	±	2.07	3.13[d]	±	1.92

[γ]Means and Standard Deviation.
[a–e] Means with different superscripts within a row indicate significant differences ($P<0.05$) based on ANOVA and Tukey's. Values are based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).
[β] Expected attribute.

[γ]Mean scores based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

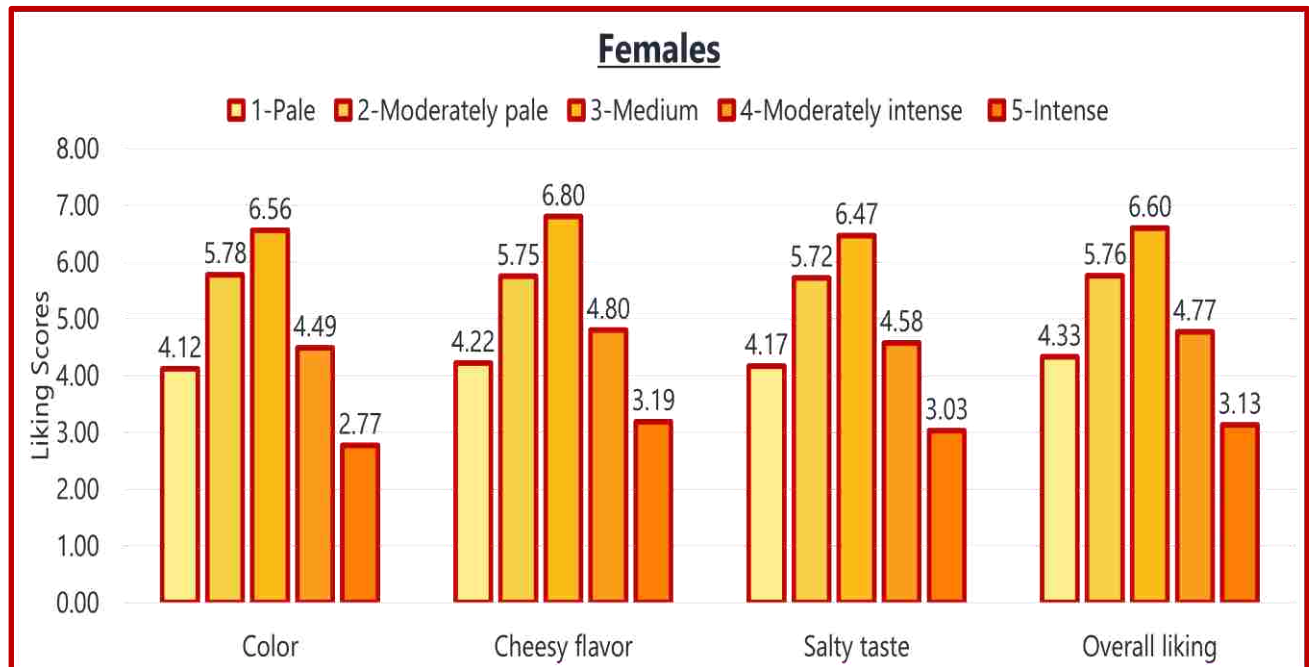Figure 3.5 –Liking scores$^\gamma$ of cheese dips with different color intensities of females, based on visual cues

Another important observation is that women presented a higher hedonic discrimination among samples than men. For all attributes, females were able to significantly perceive four different levels of visual liking, while males perceived only three hedonic levels from the same set of five cheese dip samples. For both males and females, the "medium" treatment elicited the highest liking ratings. However, females were able to perceive the visual liking of the "moderately pale" and "moderately intense" treatments differently, while for males the liking of the same two treatments did not statistically differ. Also, for males, both "pale" and "intense" treatments did not elicit significantly different scores in terms of liking. Yet for females, the "intense" treatment was most penalized in terms of visual liking for all attributes.

Observed gender differences regarding visual liking discrimination might be explained by the way females and males evolved specialized visual biases (Phan, Wager, Taylor, & Liberzon, 2002). From an evolutionary standpoint, the early labor role of females as gatherers required a more extensive level of specialization for processing visual observation. While women developed visual abilities that enhanced the identification of the form, color, and memory of food, males developed more intensive spatial skills that facilitated the hunting of animals (Hurlbert & Ling, 2007; Alexander, 2003). Consequently, females acquired a special talent for color information awareness. Moreover, the need for identification of ripe yellow fruits and red leaves hidden in green vegetation, led females to develop a special discrimination ability for red wavelengths (Alexander, 2003).

From a biological standpoint, males are more likely to present color deficiencies than females. In fact, a higher percentage of males (8%) than females (0.5%) are affected

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by red-green color blindness (NEI, 2015). Sex is determined by several genetic characteristics including the type of chromosomes: X chromosome and Y chromosome. Females have two X chromosomes, while males have one X and one Y chromosomes. This genetic difference in chromosomes is the main reason why males tend to have more color deficiencies. Sensitivity to red-green system is transmitted on the X chromosome. As males only have one set of X chromosomes, they are more likely than females to present color blindness (Alexander, 2003). This influence of genetics on color vision is consistent with evolutionary empirical theories about the ability of females to discriminate red wavelengths for seeking food. This evolutionary change may have contributed to current visual biases and product preferences.

b) Influence of gender on the expected salty taste liking

To evaluate whether gender (females vs. males) affected the expected salty taste liking of cheese dips with varying color intensities, a 2-sample t-test was performed. The visual spider plot (Figure 3.6.) indicates that gender significantly influenced the expected saltiness liking. Females generally expected a lower salty taste liking from all cheese dip samples compared to males. Treatments with a higher color concentration, "moderately intense" and "intense", were found to be statistically different across gender. These results indicate that males tend to have a higher level of acceptability for more intense colors and are expecting to like the salty taste of cheese dips with higher color intensity better than women. This finding supports Spence (2015a), who indicated that the same food color can elicit different expectations regarding the likely taste of products in different groups of consumers, in this case females and males.
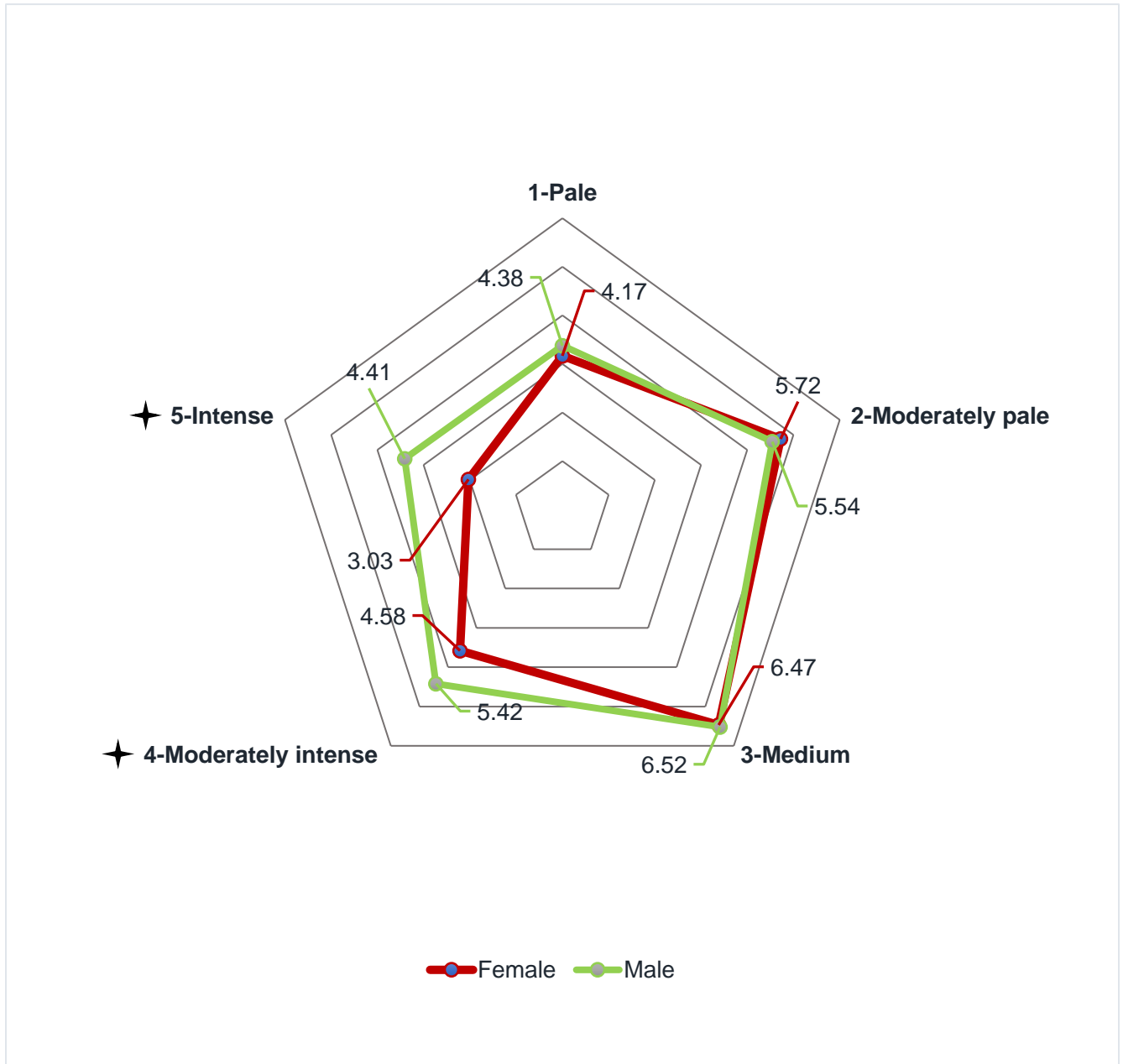
Figure 3.6. Expected salty taste liking scores[v] of females vs. males, based on visual cues

[v]Mean scores based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).
✦Treatments were perceived significantly different between females and males (a t-test, α=0.05)

c) Identifying drivers of expected attributes' liking for males vs. females and its effects on the overall visual liking of cheese dips

Consumer-driven product development requires the Research and Development (R&D) scientists to acquire detailed understanding of what consumers desire in a food product, i.e., identify what consumers expect from a product (Cardello, 1994). In addition, they must determine how product characteristics impact product acceptance, consumer expectation, and purchase decision.

All sensory attributes do not affect hedonic responses in the same way. Characteristics that contribute the most to overall product differences are considered more critical to acceptance and purchase intent. To identify the most important attributes driving expected consumer acceptance, a Multivariate analysis of variance (MANOVA) was used. This statistical technique is an extension of the ANOVA procedure that shows whether significant differences among products exist when all attributes are simultaneously considered. The Wilks's lambda P-value indicates statistical significance of product differences when all evaluated sensory characteristics are contemplated in the analysis. Subsequently, a descriptive discriminant analysis (DDA) was performed to identify which attributes contributed more to the overall product differences (Table 3.6.). The two higher canonical structures from DDA were arbitrarily selected to determine which attributes were more critical in the overall product discrimination.

For the current study, MANOVA results for both females and males indicated that cheese dips with varying yellow/orange color intensity were significantly (Wilk's lambda P-value <0.0001) different when considering all evaluated attributes simultaneously. DDA results from the first discriminant function (Can 1), which accounted for 97.8%-97.4% of

the variance explained, revealed that for both females and males, color liking was the attribute that most affected cheese dip discrimination. However, differences among gender were observed for the second most critical attribute. For females, salty taste expectation was found to be the second most important hedonic attribute, while for males overall liking was the second most important attribute contributing to the overall differences between cheese dips.

Table 3.6. The pooled within canonical structure (r's)* describing attributes that trigger group differences among cheese dips with different color intensities.

Attributes	Females (n=120)		Males (n=120)	
	Can 1**	Can 2**	Can 1**	Can 2**
Color	**0.900**	-0.122	**0.958**	-0.271
Cheesy flavor$^\beta$	0.840	0.532	0.851	-0.024
Salty Taste$^\beta$	**0.871**	0.024	0.653	-0.122
Overall liking	0.813	0.140	**0.889**	0.351
% Variance explained	**97.84%**	**1.92%**	**97.44%**	**2.06%**

*Based on the pooled within group variances with $P<0.0001$ for females, males and combined groups (general) of Wilk´s Lambda from MANOVA analysis.
**Can 1 and Can 2 refer to the first and second discriminant functions, respectively.
$^\beta$ Expected attribute.

d) Effects of visual color cues on consumers' expected saltiness intensity

A JAR (Just-About-Right) scale was used to measure the expected intensity of the attributes in relationship to the consumers' ideal intensity level. JAR data supports the product development process, since it helps R&D scientists understand which attributes need to be adjusted to achieve optimal levels, hence increasing product acceptability.

Overall frequencies (%) of female vs. male satisfaction towards salty taste expectation are shown in Table 3.7. JAR data revealed that increasing yellow/orange color intensity of cheese dips increased the expected saltiness intensity for both males and females, switching the JAR rating from "not salty enough" to "too salty". These findings indicate that there is indeed an association of color intensity with the expected salty taste. More intense colors induce higher saltiness expectations.

Table 3.7. Overall frequencies (%) of females vs. males' satisfaction towards salty taste expectation.

Treatment	Females (N=120)			Males (N=120)		
	% Not salty enough	% JAR	%Too salty	% Not salty enough	% JAR	%Too salty
5-Intense	7.5	3.3	89.2	5.8	20.0	74.2
4-Moderately Intense	4.2	36.8	59.2	5.0	52.5	42.5
3-Medium	5.8	82.5	11.7	7.5	85.8	6.7
2-Moderately Pale	25.8	69.2	5.0	42.5	54.2	3.3
1-Pale	70.8	18.3	10.8	67.5	25.8	6.7

Gender differences also impacted salty taste intensity expectations. For most males, the "moderately intense" treatment was perceived as ideal in terms of saltiness, since 52.5% indicated that the salty taste was expected to be just about right. In contrast, most women (59.2%) expected the "moderately intense" cheese dips to be too salty. In fact, there is a large difference between females and males frequency regarding the "too salty" rating for the most intense treatments. Respectively, 39% and 20% more females

than males indicated the "moderately intense" and "intense" treatments are expected to be too salty. Regarding the expected salty taste intensity elicited by paler treatments, most males and females expected the "moderately pale" cheese dip to have a just-about-right salty taste. However, a higher percentage of females (28% more than males) perceived this treatment as ideal in terms of saltiness. These results are consistent with the hedonic responses observed in section 3.3.3b. The fact that women expect more intense treatments to be saltier than males may have influenced the salty taste liking differences observed between genders.

Variation in salty taste expectations between males and females, as influenced by color, may be related to several biological differences across gender. The best phenotypic markers of variation in taste include the density of taste papillae, thermal tasting, and perceived bitterness of propylthiouracil (PROP) (Hayes et al., 2010). Research has shown that individuals who detect a bitter taste from PROP (supertasters) are more sensitive to changes in salt concentration (Hayes et al., 2010). For instance, a study showed that supertasters preferred beef broths with less salt content compared to regular tasters who do not have the phenotype to detect a bitter taste from PROP (Lee, Prescott, & Kim, 2008). Females are more likely to be super tasters than males (Essick, Chopra, Guest, & McGlone, 2003; Bartoshuk, Duffy, & Miller, 1994) and have also been found to possess higher numbers of fungiform papillae and taste buds (Bartoshuk, Duffy, & Miller, 1994). These physiological differences might explain why women tend to be more responsive to changes in sodium concentrations and perceive significantly more saltiness from high-sodium products than men (Hayes et al., 2010).

Considering females' special sensitivity to salty taste, the findings from this section suggest that women might also be more likely to present taste-color cross-modal interactions. In general, intensity perception is directly correlated with the firing rate of nerve fibers. Research has demonstrated that increasing intensity of a sensory input increases neural firing regardless of the sensory system (Spence et al., 2010). This indicates that increasing the stimulus intensity of a sensory modality may lead to cross-modal correspondences with the intensity of a sensory input of another sense (Spence et al., 2015). The fact that a lower stimulus can provoke a higher saltiness perception in females than males, may indicate that a less intense color input is needed to elicit an ideal expected salty taste in females. This supposition goes beyond the scope of this study and more research is needed to validate this hypothesis.

e) **Effects of color intensity on the overall liking of cheese dips**

JAR scales can also be used in combination with acceptance/hedonic scales as a tool to recognize how the overall liking of the product was affected when attributes are perceived as not ideal. In this way, it becomes easier to identify in which direction (increase or decrease) attributes should be adjusted (Rothman & Parker, 2009). As found from MANOVA and DDA analyses, color was the most important attribute for the overall product discrimination, followed by the salty taste expected liking for females. Therefore, a penalty (mean-drop) analysis was performed to determine how the overall liking score of the product was affected when the most critical attributes (color and salty taste) were perceived or expected not to be ideal ("too weak" or "too strong").

The American Society for Testing and Materials (ASTM) suggest a 20% cutoff of respondents to eliminate less impactful treatments (Rothman & Parker, 2009). Attributes

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with large penalties and number of responses are considered the most concerning issues of the product, which can be identified in the right lower quadrant of the penalty plot (Figure 3.7.). Attributes with a mean drop greater than 2 points are considered very concerning (Rothman & Parker, 2009).

Mean-drops reported in the penalty plot indicate that the overall liking score of the product was highly penalized when attributes were not ideal. For example, when the color of the most intense treatment was perceived as "too strong" by females, the overall liking score of cheese dips decreased by almost 4 points (Figure 3.7.). These results demonstrate that color can have a dramatic impact on overall product acceptability. Having a color that was perceived as not ideal ("too strong" for females) can cause the overall liking rating to drop from "like very much" (rating of 8 on a 9-point hedonic scale) to "dislike slightly" (rating of 4 on a 9-point hedonic scale).

Overall, very large mean drops values of "too strong" yellow/orange color (3.99) were associated with "too strong" salty taste (2.45) for females compared with 3.48 and 2.02, respectively, for males. Interestingly, for women, when attributes of all treatments were perceived as not ideal, there was a larger decrease in the overall liking score of cheese dips compared to males. This indicates that, compared to males, females tend to penalize products more when attributes are perceived as not ideal. This tendency was also observed for females in liking scores and JAR ratings from products that were expected to be disliked the most. It is possible that the tendency for women to give lower ratings than males is related to how females emotionally respond to negative stimuli (Stevens & Hamann, 2012).

Emotional responses elicited by visual cues have been found to activate structures of the limbic system of the brain (Phan et al., 2002). Several studies have reported that when females and males experience negative emotions, females exhibit a greater activation of the right amygdala and cingulate cortex (Steven & Hamann, 2012; Klein et al., 2003; Wrase et al., 2003; Phan et al., 2002). These brain areas are associated with learning, memory, and the emotional quality of taste. A study evaluating the emotional valence (positive or negative emotion) of visual cues on functional magnetic resonance imaging (fMRI), revealed that brain activation of the amygdala and anterior cingulate was stronger in females when negative visual cues were evaluated (Klein et al., 2003). In another a study by Zald et al. (1998), where females tasted an aversive saline solution and a control solution containing water, it was observed that the right amygdala, OFC, cingulate cortex, and hippocampus presented higher activity in response to the saline solution. Thus, both gustatory and visual stimuli have been shown to activate similar areas of the brain involved in memory and emotions, with females generally exhibiting a higher activity in response to aversive stimuli.

Findings from these cognitive neuroimaging studies and the theory of statistical regularity, in which colored foods are more likely to be intensely flavored (Spence et al., 2015; Spence et al., 2010), may suggest that females tend to present higher generalized associations between color intensity and taste/flavor concentrations. These suggestions may explain why females expected a higher saltiness intensity than males from the same intensely colored cheese dips. Also, the fact that females exhibit higher brain activity of structures involved in the memory of taste in the presence of aversive cues, may explain
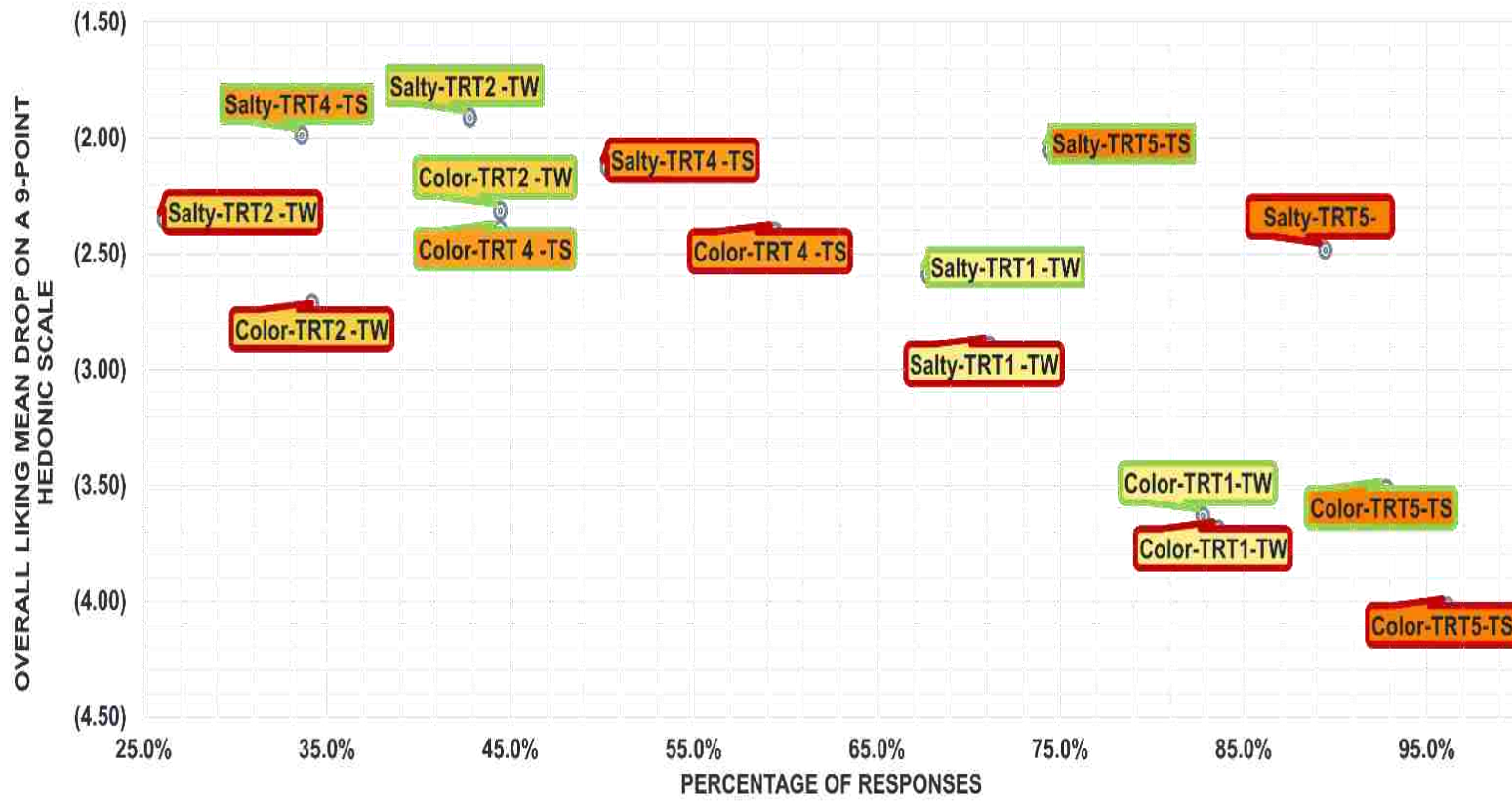
Figure 3.7–Mean drop of the overall liking score when attributes were not ideal (too weak (TW)/too strong (TS)

*TS: too strong, TW: too weak

why they tend to penalize the overall liking of the product more than males, when the attributes are expected to have an aversive taste.

3.3.4 Effects of color intensity on the purchase intent of cheese dips

Evaluating how likely consumers are to purchase a product just by visual inspection is critical for development of reduced-sodium products, especially when considering color as a strategy to increase saltiness perception. Even if color intensity is found to increase salty taste, it would be problematic if consumers were not willing to purchase products with the color that exhibited the highest saltiness perception.

Table 3.8. Multiple comparison[†] of consumers' willingness to purchase scores[γ] for cheese dips with different color intensities

Females n=120						Males n=120					
Treatment[β]	5	1	4	2	3	**Treatment[β]**	5	1	2	4	3
Rank sum*	283	319	353	403	442	**Rank sum***	302	314	379	383	422
Differences versus						Differences versus					
5		36	**70**	**120**	**159**	5		12	**77**	**81**	**120**
1			34	**84**	**123**	1			**65**	**69**	**108**
4				**50**	**89**	2				4	43
2					39	4					39
Critical difference = 48[δ]						**Critical difference = 48[δ]**					

[γ] Scores based on a 5-point ranking scale being 1 definitely will not buy and 5 definitely will buy.
[β] Treatments are organized from the lowest (definitely will not buy) to the highest (definitely will buy) scores.
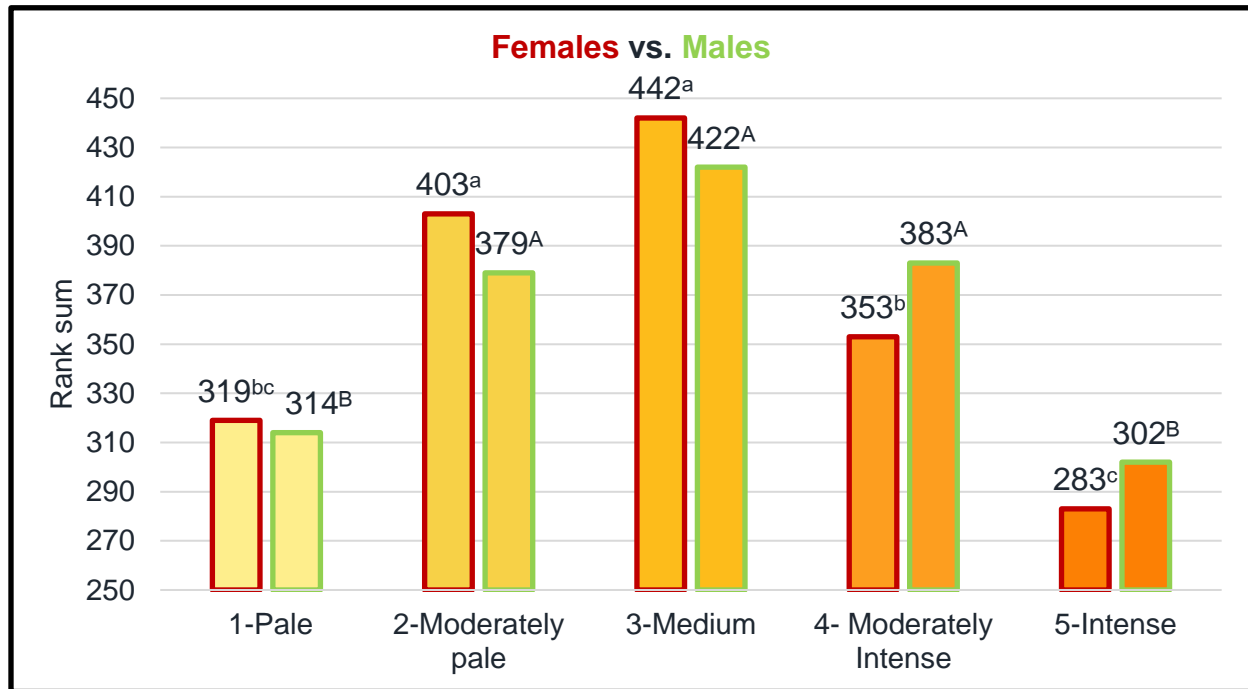*Rank sum difference
[†] Based on Christensen´s and others (2006) multiple comparison procedure for analysis of ranked data.
[δ]Critical values (CV) of differences between rank sums P=0.05 were calculated as CV = $4.3553p^{0.5012}$ being p the number of panelists.
Bolded values indicate significant differences within pairs

To evaluate consumers' willingness to purchase cheese dips with varying yellow/orange color intensities, a 5-point ranking scale was selected as it gives a relative magnitude of difference between treatments. The purchase intent scores of the treatments were consistent with findings from hedonic and JAR evaluations. Overall, panelists were less willing to buy products with the most "pale" and "intense" colors (Figure 3.8.). For both females and males, the "medium" treatment elicited the highest purchase intent. Gender differences also impacted the willingness to purchase cheese dips, with males being more willing to purchase cheese dips with more intense colors.

[a-c] Means with different superscripts within the females rank sum indicate significant differences based Christensen´s and others (2006) multiple comparison procedure for analysis of ranked data
[A-B] Means with different superscripts within the males rank sum indicate significant differences based Christensen´s and others (2006) multiple comparison procedure for analysis of ranked data

Figure 3.8 Rank sum of females' vs. males' willingness to purchase cheese dips

To test whether rank sum differences between treatments were significantly different, Christensen's et al. (2006) multiple comparison procedure of ranked data was

used. Based on statistical analysis, males' willingness to purchase cheese dips was the same for products with a chroma values between 45 and 66 ("moderately pale" to "moderately intense"). However, males were significantly ($p < 0.05$) less willing to purchase products with "pale" (chroma ≤ 30) and "intense" (chroma ≥75) colors. On the other hand, women were found to be more selective in their willingness to purchase cheese dips with different color intensities. For females, the most intense treatment significantly elicited the lowest purchase intent, while cheese dips between "medium" and "moderately pale" (45 ≤ chroma ≤ 65) color intensities exhibited the highest willingness to purchase.

3.4.   Summary of results and conclusion

Yellow/orange color intensity of cheese dips influenced the liking, willingness to purchase, and salty taste expectations of cheese dips. Color intensity, particularly pale and most intense colors, significantly decreased liking scores of all attributes. Higher scores were generally observed for MM than FM. Overall, increasing yellow/orange color intensity increased the expected saltiness intensity, switching the JAR rating from "too weak" to "too strong." FM perceived cheese dips with more intense yellow/orange color to be saltier than MM, and they were more willing to purchase samples with less intense yellow/orange dips. Large mean drops values of "too strong" yellow/orange color were associated with "too strong" salty taste for both females and males. However, females tended to more strongly penalize the overall liking of products when attributes were not ideal.

In this study, yellow/orange color intensity was observed to influence salty taste expectations of cheese dips (the more intense color, the saltier taste expectation). Gender

differences were also found to impact salty taste expectation, with FM perceiving cheese

dips with more intense yellow/orange color to be saltier than MM.

3.5.   References

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CHAPTER 4. INFLUENCES OF SPICINESS AND VISUAL COLOR CUE ON SALTY TASTE INTENSITY PERCEPTION IN REDUCED SODIUM CHEESE DIPS

4.1.   Introduction

Our previous study revealed that yellow/orange color intensity influenced salty taste expectations, visual product liking, and purchase intent (PI) of cheese dips. However, the effects of color intensity on actual taste, flavor perception, and acceptability of cheese dips have not been reported. Research has shown that high product expectations will likely enhance purchase intent (Yeomans et al., 2008). Though, if the sensory and hedonic expectations are consciously not met after tasting the product, rejection will likely occur. Disconfirmation of expectations can also result in product satisfaction if a negative disconfirmation is experienced (Expectations > Baseline) and assimilation effects occur (Cardello, 1994), i.e., perceiving a higher saltiness intensity from products that are expected to be saltier.

Findings from the first study showed a promising opportunity for increasing salty taste perception in cheese dips, since color intensity influenced salty taste expectations. However, although greater color intensity increased saltiness intensity expectations, overall acceptability and purchase intent of the product decreased for the most intense colors. Therefore, even if assimilation effects for the salty taste perception occur, there is a risk that consumers will assimilate their low hedonic expectations from the most intense colors.

On the other hand, recent studies have suggested that spicy compounds, particularly capsaicin, may increase saltiness perception and acceptability of products. A recent study by Li et al. (2017) showed that consumption of spicy foods increases

metabolic activity of the OFC, a region of the brain associated with palatability and acceptability of foods (Wainford, 2017). These authors also demonstrated that when salt is consumed in combination with capsaicin, the neural response to salt can be enhanced. This evidence, of the ability of spicy compounds to influence the neural processing of salty taste, provides a basis for exploring the use of spicy compounds to enhance acceptability of reduced-sodium products (Li et al., 2017). Also, current market growth and demand for products containing spicy ingredients suggests that the use of spice would be a feasible strategy to apply in the food industry (Kalsec®, 2017).

The use of spicy compounds in combination with the color intensity strategy may contribute to increases in saltiness perception, acceptability, and willingness to purchase reduced-sodium products. However, effects of yellow/orange color and spiciness intensity on actual taste/flavor perception of cheese dips have not been reported. Thus, the general objective of this study was to evaluate the combined effects of color (yellow/orange) and spiciness (cayenne) intensity on saltiness, liking, and PI of reduced-sodium cheese dips.

4.2.   Materials and methods

4.2.1. Formulation

Using a factorial arrangement, 9 cheese dips at a fixed salt concentration of 218.3 mg sodium/serving (32g) were manufactured [3 spiciness levels: none, medium, intense x 3 yellow/orange color intensities: pale, medium, intense]. Ingredients for the cheese dip formulation base included: whole milk (Great Value, Walmart, USA), sharp cheddar cheese (Great Value, Walmart, USA), cream cheese (Original Philadelphia cream

cheese, Kraft Heinz Company, Chicago, IL, USA), cheddar cheese flavor 11278 (First Choice Ingredients, Germantown, WI, USA), natural parmesan cheese flavor 491K (First Choice Ingredients, Germantown, WI, USA), sodium citrate (Modernist Pantry, Eliot, ME, USA), corn starch (Argo, ACH Food Companies Inc, Oakbrook Terrace, IL, USA), and table salt (Table 4.1.). Figure 4.1. shows the base cheese dip manufacturing process used for all treatments.

Table 4.1. Cheese dip formulation ingredients and percentages for a small batch

Ingredients	Small batch (g)	Formulation %
Cooked milk/cayenne infused milk	146.25	48.75
Cream cheese	56.15	18.72
Cheddar cheese	90.00	30.00
Parmesan cheese concentrate 400	1.65	0.55
Natural cheddar cheese flavor 239K	1.65	0.55
Salt	0.16	0.05
Sodium Citrate	2.55	0.85
Starch	1.50	0.50
Total weight	**300**	**100**
FINAL (After cooking)	**245.0**	**81.67 (Yield)**

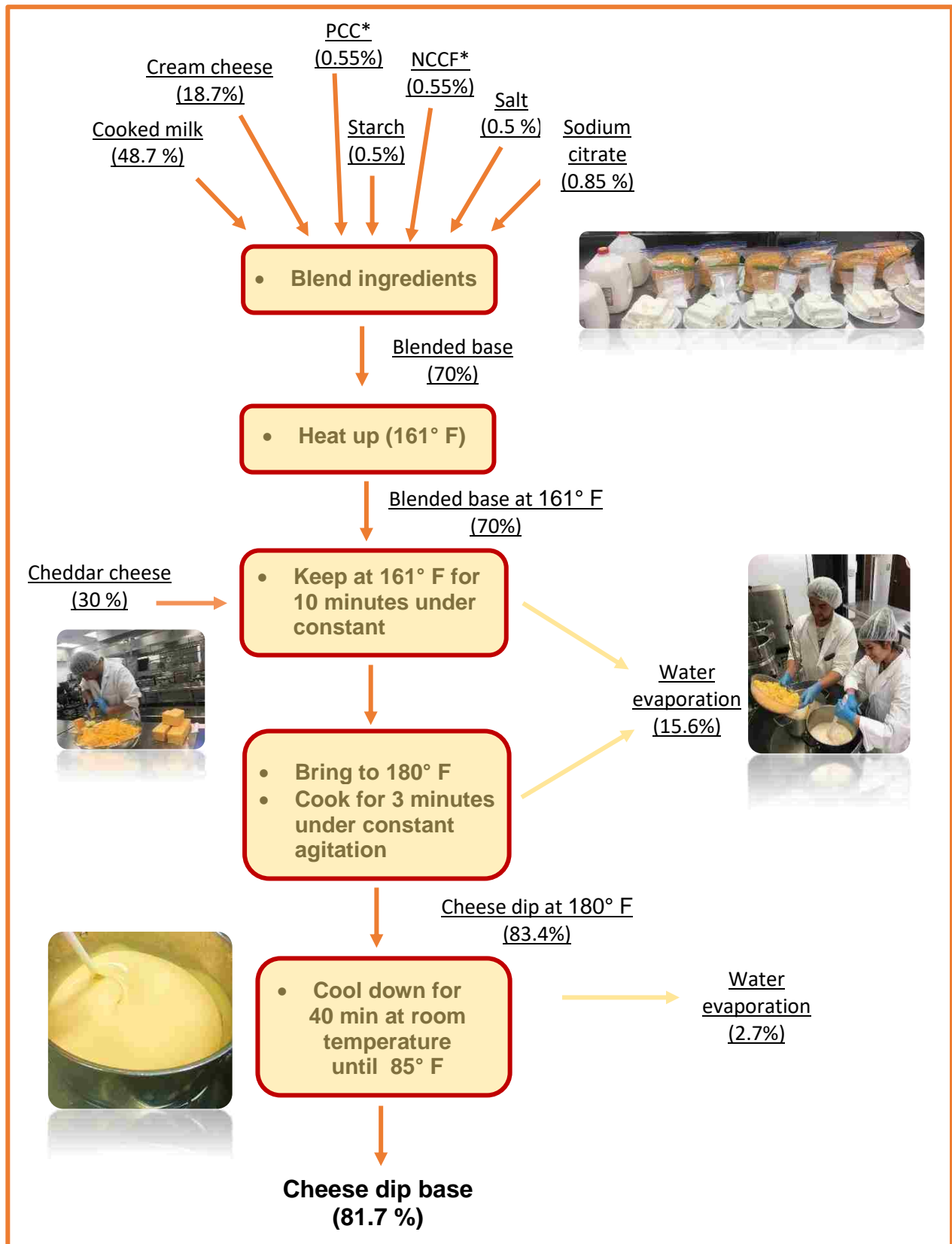*Formulation percentages are based on the total weight of the product prior to cooking

Figure 4.1. Cheese dip manufacturing process

4.2.2. Spiciness level and color intensity determination

To create the different spiciness levels, ground cayenne pepper was used to infuse the milk contained in the treatments with "medium" and "high" spiciness levels (refer to Figure 4.2. for the process). For the "none" spiciness level, whole milk (without cayenne) was also cooked following the same procedure of the infused milk to minimize variation among treatments. All treatments followed the same procedure and contained the same ingredients except for the cooked milk used. Treatments with "none" spiciness were formulated with 100% cooked whole milk, "medium" spiciness with 50% cayenne infused milk and 50% cooked whole milk, and "high" spiciness with 100% cayenne infused milk (see Table 4.2. for treatment identification).
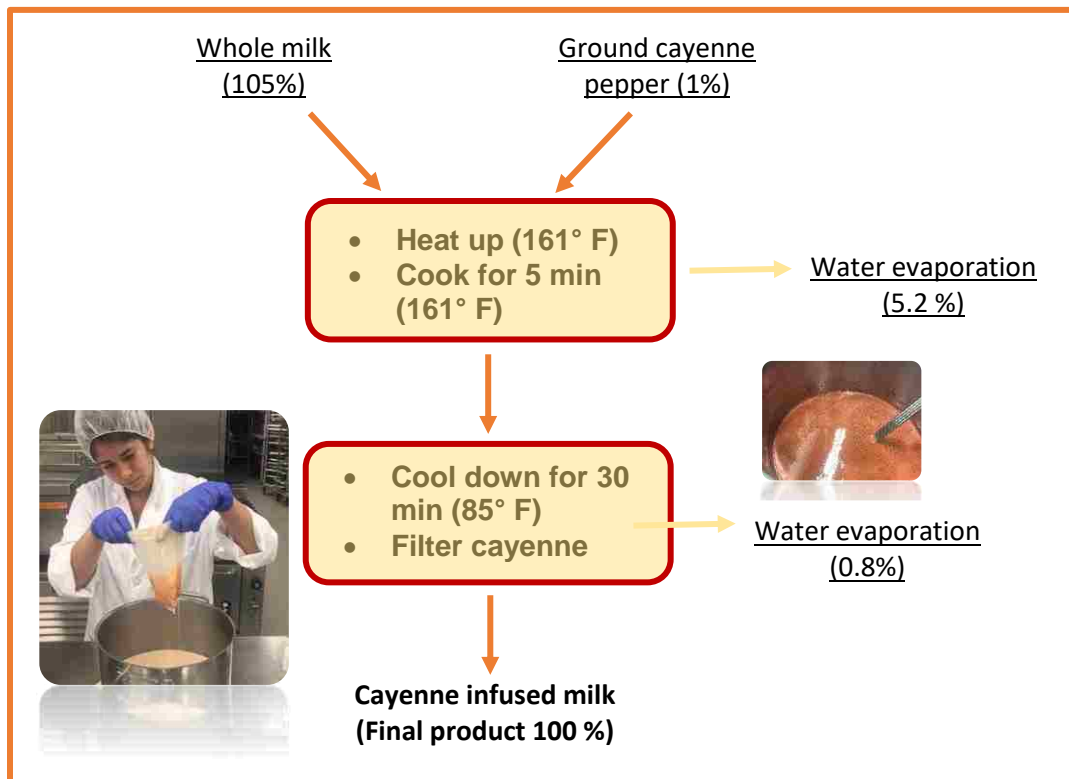

Figure 4.2. Cayenne infused milk process flow chart

Table 4.2. Cheese dip treatment identification by spiciness level

Treatments	Spiciness	Whole milk %	Infused milk %
1-2-3	None	100	0
4-5-6	Medium	50	50
7-8-9	High	0	100

On the other hand, color intensity levels were obtained by adding different concentrations of liquid annatto to the "medium" and "intense" cheese dip treatments. No annatto was added to the "pale" color treatments as the cheese used in the base formulation had an inherent pale yellow/orange color. After the cheese dip base was cooled, batches were separated into three equal parts and annatto was added in percentages according to Table 4.3. Actual colors of the cheese dips are shown in Figure 4.3.

Table 4.3. Treatment identification by color

Treatment	Sample description	% of colorant used*
1-4-7	Pale	0
2-5-8	Medium	1.5%
3-6-9	Intense	4.2%

Figure 4.3. Actual treatment colors

4.2.3. Sodium determination and comparison with commercial cheese dips

Sodium content of the cheese dips was determined using a calculation based on the sodium content claimed on the labels of the ingredients used (Table 4.4.). Sodium content per gram of each ingredient was calculated by dividing the amount of sodium (mg) per serving by serving size (grams). As detailed in Table 4.5., the sodium content per gram of each ingredient was then multiplied by the amount of ingredient used to obtain the total sodium content in the small batch (245 grams). Total sodium content in the small batch was divided by 245 grams to obtain the amount of sodium per gram of cheese dip and then multiplied by 32 grams to determine the amount of sodium per serving size (Table 4.6.).

Table 4.4.Sodium content (mg) in ingredients used for cheese dips

Sodium content				
Ingredients		**Serving size(g)**	**Na (mg)/serving**	**Na (mg)/g ingredient**
Milk	Whole milk	240	120	**0.50**
	After infusion/cooking*	225.6	120	**0.53**
Cream cheese		28	105	**3.75**
Cheddar cheese		28	180	**6.43**
Parmesan cheese concentrate 400		100	1888.5	**18.89**
Natural cheddar cheese flavor 239K		100	1969.9	**19.70**
Salt		1.5	590	**393.33**
Sodium Citrate		2.5	665	**266.00**
Starch		8	0	**0.00**

*Whole milk lost 6% of water after the cooking process used for cayenne infusion

Table 4.5.Cheese dip base formulation and sodium content per small batch (245g)

Cheese dip base formulation				
Ingredients	Small batch (g)	Formulation %	Na (mg)/g product	Na (mg) in product used for small batch**
Cooked milk	146.25	48.75	0.53	77.79
Cream cheese	56.15	18.72	3.75	210.58
Cheddar cheese	90.00	30.00	6.43	578.57
Parmesan cheese concentrate 400	1.65	0.55	18.89	31.16
Natural cheddar cheese flavor 239K	1.65	0.55	19.70	32.50
Salt	0.16	0.05	393.33	62.54
Sodium Citrate	2.55	0.85	266.00	678.30
Starch	1.50	0.50	0.00	0.00
Total weight	300	100	Na (mg) content in 245g	
FINAL WEIGHT* (After cooking)	245.0	81.67 (Yield)		1671.44

Table 4.6. Sodium content in cheese dip

Na (mg) content in 245g	Na (mg) content/g	Na (mg)/ serving size (32g)
1671.4	6.8	**218.3**

The manufactured cheese dip had a lower amount of sodium per serving size compared to the average level found in 15 leading commercial brands. The following formula was used to quantify the percent reduction in sodium per serving size:

$$\% \text{ reduction} = \frac{(\text{Na in brand} - \text{Na in LSU}) * 100}{\text{Na in brand}}$$

A summary of all percent reduction calculations is provided in Table 4.7. The average percent reduction of sodium per serving size compared to the 15 leading commercial brands was 33 percent.

Table 4.7. Cheese dip sodium content compared to leading brands

	Brand	Na (mg)/g	2 Tbsp (32g)	% Reduction*
REF	**Manufactured cheese dip**	6.8	218.3	N/A
1	Velveeta Cheese Sauce	14.3	458.5	52.4
2	Cheez Whiz	12.8	409.6	46.7
3	Kraft Old English Spread	17.8	569.6	61.7
4	Tostitos Medium Salsa Con Queso	8.2	263.5	17.2
5	Frito Lay Jalapeno Cheddar Flavored Cheese	6.9	220	0.8
6	Ragu Cheese Sauce	7.3	235	7.1
7	Fritos Flavored Cheese Dip	6.9	220	0.8
8	Great Value Melt 'n Dip Cheese	12.8	410	46.8
9	Ricos Gourmet Nacho Cheddar Cheese Sauce	8.4	270	19.2
10	On The Border Monterey Jack Queso	8.1	260	16.1
11	Herdez Queso Dip	9.1	290	24.7
12	Taco Bell Salsa Con Queso	13.6	436	49.9
13	Pace Salsa Con Queso Dip	8.4	270	19.2
14	Puck Pure and Natural Cheese Cream Spread	10.3	331	34.1
15	Great Value Salsa Con Queso Cheese Dip	8.2	263.5	17.2
	AVERAGE	**10.2**	**327.1**	**33.3**

4.2.4. Color measurement

The color of each treatment was measured in triplicates by reflectance using a benchtop spectrophotometer (model CM-5, Konica Minolta, Jakarta Raya, Indonesia). Color

measurements were reported in L*, a*, b*, hue, chroma, and ΔE values. Refer to chapter 3 section 3.2. for detailed color measurement methodology.

4.2.5. Blind test tasting

It has been reported that the use of colorant may affect saltiness perception (Harrar et al., 2011). Therefore, it was necessary to ensure that the annatto used to change the color of the cheese dips did not affect the salty taste perception. To test whether annatto affected salty taste, a blind test tasting was performed using a 2-AC (alternative choice) discrimination test. For this pre-trial, cheese dips with no annatto added ("pale" treatments) were compared against cheese dips containing the highest concentration of colorant ("intense" treatments).
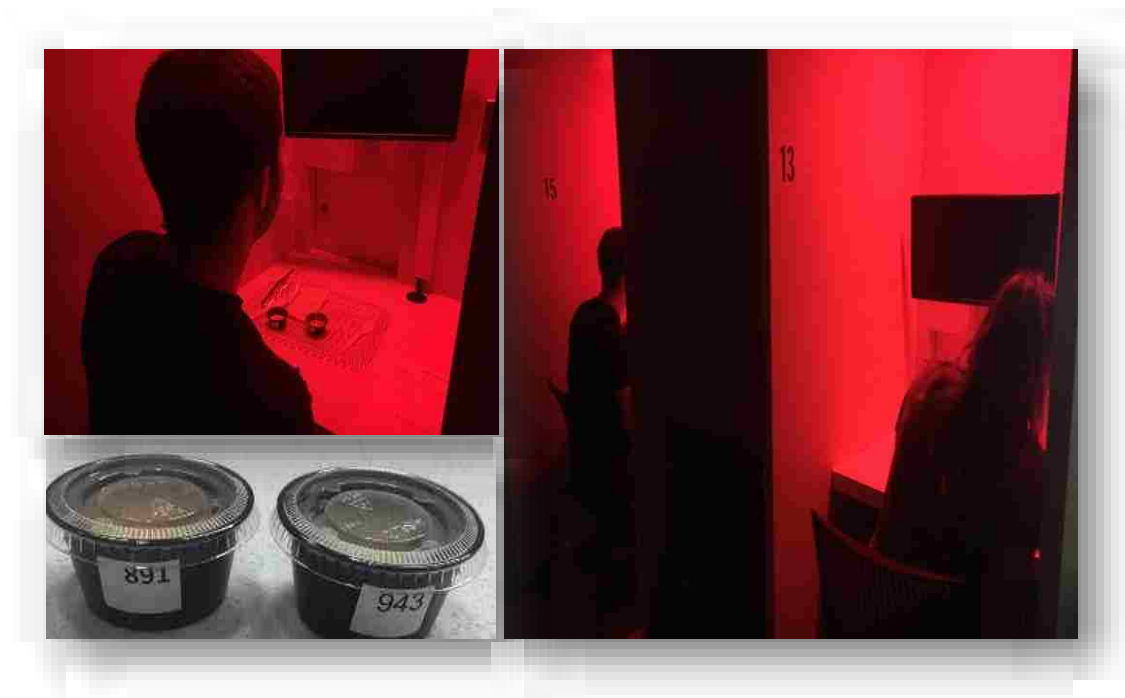

Figure 4.4.- Blind taste testing

The 2-AC procedure was selected for this study as it has been found to be slightly more powerful than the traditional 2-AFC (alternative forced choice) method (Gridgeman, 1959). In the 2-AC discrimination method, panelists must first determine if there is a difference between the two samples being tested in terms of saltiness. If subjects are able to find a difference, they must select which sample is stronger in the sensory dimension (Braun, Rogeaux, Schneid, O'Mahony, & Rousseau, 2004). Different from the 2-AFC procedure, the 2-AC method allows consumers to select if no difference was perceived between the two samples (Ennis & Ennis, 2010). For this reason, a Thurstonian model should be used for analysis as it considers both the size of the difference between samples and the likelihood of producing "not different" responses (Ennis & Ennis, 2010).

A total of 20 panelists with some prior sensory testing experience were recruited from the School of Nutrition and Food Sciences at LSU. Panelists evaluated the two cheese dip samples under fluorescent red lights to mask the color intensity of the samples (Figure 4.4.). 20 grams of sample were served into black 2 oz. cups and were distributed to assessors following a randomized and balanced design. Panelists were asked to taste the two samples from left to right and to have water and unsalted crackers between samples to cleanse their palate. Evaluators were then asked to indicate which sample was the saltiest. If no difference was noticed, they could select "not different" as an option. Results from the 2-AC discrimination test were analyzed using the Thurstonian approach (Thurstone, 1927).

4.2.6. Blind test results

Table 4.8. shows the values of choice counts for the treatments and "not different" option. As seen, eight subjects selected the "intense" treatment, while ten chose the "pale" treatment as the saltiest. Two assessors, which accounted for ten percent of the subjects, selected the "not different" option. Hypothesis testing for this particular study can be seen as followed:

H0:   A (pale) = B (intense)

Ha: A (pale) ± B (intense)

In terms of saltiness

Table 4.8. Values of choice counts

Treatment	Choice	Choice counts
Intense	891	8
Pale	930	10
Not different		2

Hypothesis testing was performed following the procedure referenced by Ennis and Ennis (2010). To test the hypothesis, the observed choice counts and the critical value (values of choice counts) from the relevant Thurstonian 2-AC significance table (105) were compared. The critical value for 20 panelists with an α = 0.05 (one tailed) and observed "not different" proportion of 10% was 13. To declare significance, the critical value must be met or exceeded. In this case, the critical value (13) was greater than the observed value (10), and so the null hypothesis was not rejected. These results indicate

that no statistically significant differences in terms of saltiness were found between the "pale" and "intense" treatments when evaluated under a blind condition.

4.2.7. Consumer test and participants

The sensory evaluation study protocol was approved by the Institutional Review Board of Louisiana State University (LSU) Agricultural center (IRB# HE15-9). A total of 79 participants were recruited from a pool of LSU students, faculty, and staff. All participants met the following criteria: (1) at least 18 years of age, (2) were not allergic to any of the ingredients used in the cheese dips or unsalted crackers (3) did not present any visual impairment or color blindness, (4) Availability to come three different days for 7-10 minutes to complete the survey. Consumers were required to read and sign a consent form (IRB # HE 15-9) before the study. The questionnaire was completed electronically using the Compusense® five software (Compusense® five, Release 5.6 with Compusense Inc., Guelph, Ontario) at the Sensory Science Laboratory of the School of Nutrition and Food Sciences, LSU, LA., U.S.A.

Panelists evaluated all treatments in three sessions (three treatments each session) with a fixed level of spiciness. The spiciness level of days 1, 2 and 3, were "none", "medium", and "high", respectively. Samples were evaluated in a randomized complete block desing. Unsalted tortilla chips were used as a carrier for the cheese dips. Panelists were asked to evaluate the samples from left to right and to have unsalted crackers and water in between samples to cleanse their palate. By visual observation, consumers rated color liking (a 9-point hedonic scale), expected salty taste, cheese flavor, and spiciness intensity using a 5-points JAR scale. After tasting the samples,

subjects indicated liking (a 9-point hedonic scale) and intensity (a 5-points JAR scale) of salty taste, cheese flavor, and spiciness. PI was evaluated using a binomial scale (yes/no) before and after tasting the products.

4.2.8. Data analysis

To evaluate if increasing the color or spiciness intensity significantly affected the liking scores of the tested attributes, a two-way ANOVA (a Glimmix procedure) and a Post-hoc Tukey's Studentized range test ($\alpha = 0.05$) were performed. JAR data were analyzed using a penalty analysis to investigate how the overall liking score of the products was affected when attributes were expected to be not ideal. Finally, data from color measurements were analyzed using a one-way ANOVA (a Glimmix procedure) followed by a Post-hoc Tukey's Studentized range test ($\alpha = 0.05$). Statistical analyses were performed using the SAS 9.3 software (Statistical Analysis System NC, USA).

4.3. Results and discussion

4.3.1. Effects of colorant concentration and cayenne on instrumental analysis

The effect of colorant and cayenne infused milk concentration on color values of cheese dips is presented in Table 4.9. Addition of annatto significantly changed color parameters measured by instrumental analysis across color levels . Increasing annatto concentration significantly ($P>0.05$) increased redness (+a) and yellowness (+b value) of cheese dip samples. The hue value of the samples, which ranged from 65.6 to 67.9, minimally changed across all treatments. Overall, increasing color intensity slightly decreased the hue values. This shows that samples with higher color intensity presented a slightly redder color shade. On the other hand, color intensity also increased from the

Table 4.9. Instrumental analysis of cheese dip samples with different color and spiciness level

Treatments			L*			a*			b*			Hue[β]	Chroma[δ]	ΔE
P	N	T1	80.2[ab]	±	0.03	66[ed]	31.9[h]	N/A	29.1[g]	±	0.1	66[ed]	31.9[h]	N/A
	M	T4	82.3[a]	±	0.02	67.3[ba]	33.1[h]	2.5	30.5[gf]	±	0.07	67.3[ba]	33.1[h]	2.5
	H	T7	77.05[c]	±	0.08	67.9[a]	34.7[g]	4.4	32.1[f]	±	0.04	67.9[a]	34.7[g]	4.4
M	N	T2	76[c]	±	0.11	66[ed]	47.6[f]	16.3	43.5[e]	±	0.08	66[ed]	47.6[f]	16.3
	M	T5	77.5[bc]	±	0.02	66.4[bcd]	49.3[e]	17.6	45.2[d]	±	0.17	66.4[bcd]	49.3[e]	17.6
	H	T8	72.5[d]	±	0.01	66.9[bc]	51.6[d]	21.1	47.4[c]	±	0.07	66.9[bc]	51.6[d]	21.1
I	N	T3	72.2[d]	±	0.10	65.9[ed]	63.9[c]	32.9	58.3[b]	±	0.02	65.9[ed]	63.9[c]	32.9
	M	T6	71.9[d]	±	0.03	65.6[e]	65.5[b]	34.7	59.7[b]	±	0.25	65.6[e]	65.5[b]	34.7
	H	T9	70.2[d]	±	2.95	66.2[ecd]	67.3[a]	36.8	61.6[a]	±	1.76	66.2[ecd]	67.3[a]	36.8

[a-h] Indicate significant differences (P<0.05) among samples based on ANOVA and Tukey's post-hoc test

[ɸ]Mean ± standard deviation from three independent replications

[β]Calculated as arctan (b*/a*); [δ] Calculated as $\sqrt{a^{*2}+b^{*2}}$

"pale" (chroma: 31.9-34.7) to the "intense" (Chroma: 63.9-67.3) cheese dip treatments. Overall, if $\Delta E > 2.3$ consumers can discern color difference.

On the other hand, increasing amount of cayenne infused milk increased the chroma values within color levels due to the inherent shade of the cayenne. Nevertheless, color intensity of samples differed significantly between color levels regardless of the addition of cayenne. These results indicate that treatments significantly differed in yellow/orange color intensity at each color level while the spectrum of the color minimally changed when increasing annatto concentration.

4.3.2. Influence of color and spiciness intensity on cheese dips' liking scores

Liking mean scores and standard deviations of salty taste, cheese flavor, spiciness, and overall liking are shown in Table 4.10. Based on a two-way ANOVA and α=0.05, the acceptance of the salty taste, cheese flavor, and overall liking of cheese dips were not significantly affected by color intensity, spiciness intensity or the interaction between the two conditions. Spiciness liking scores significantly ($p<0.05$) differed when varying spiciness levels but not when color intensity was modified. Even though, as indicated by statistical analysis, color and spiciness intensity did not influence salty taste liking, trends seen in this study imply that some interrelationship between saltiness, color, and spiciness may exist.

4.3.3. Effects of color intensity on the salty taste liking

Although the salty taste liking score was not statistically significant, results showed an interesting trend (Figure 4.5.). Overall, at all spiciness levels, increasing color intensity
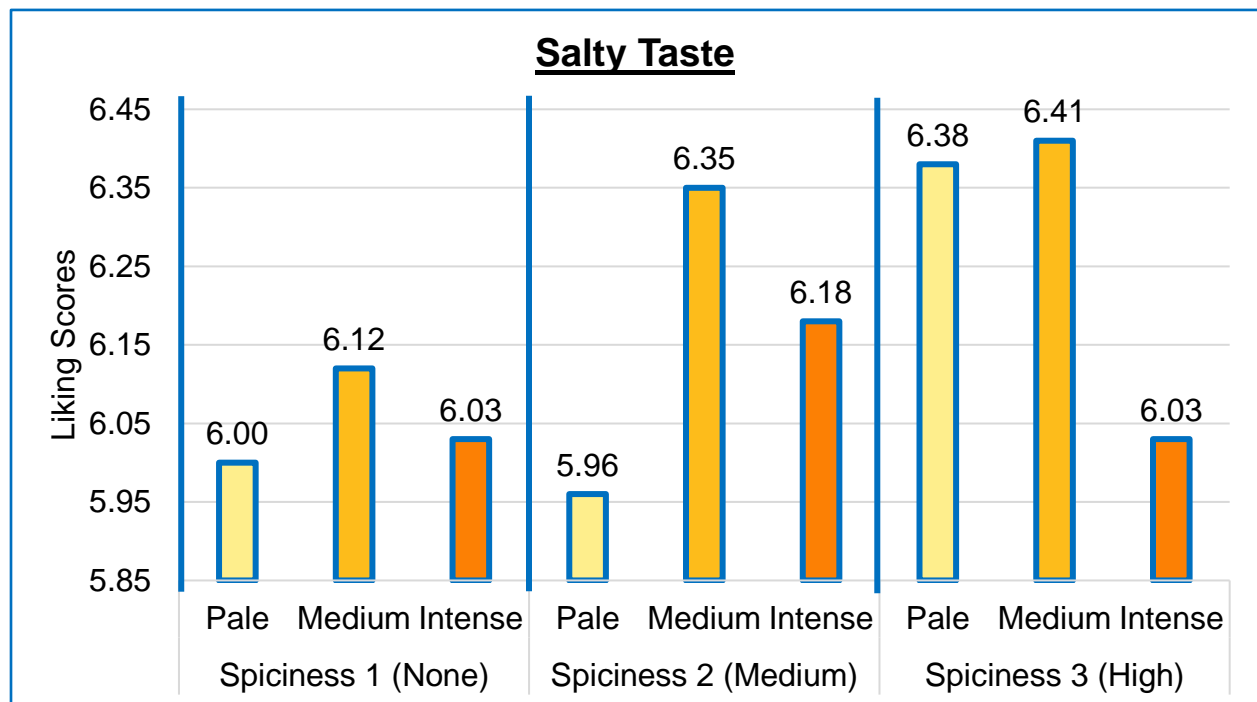
Table 4.10.Liking scores[y] of cheese dips with different color and spiciness intensities

Variables	Pale color			Medium color			Intense color		
	Spiciness 1	Spiciness 2	Spiciness 3	Spiciness 1	Spiciness 2	Spiciness 3	Spiciness 1	Spiciness 2	Spiciness 3
Salty taste*	6.00 ± 1.93	5.96 ± 1.84	6.38 ± 1.61	6.12 ± 1.67	6.35 ± 1.44	6.41 ± 1.50	6.03 ± 1.68	6.18 ± 1.62	6.23 ± 1.87
Cheese flavor*	5.97 ± 1.93	6.18 ± 1.68	6.41 ± 1.71	6.53 ± 1.62	6.49 ± 1.38	6.37 ± 1.70	6.41 ± 1.59	6.37 ± 1.66	6.19 ± 1.64
Spiciness	5.17[B] ± 1.89	5.99[A] ± 1.86	6.04[A] ± 2.00	5.53[B] ± 1.68	6.19[A] ± 1.66	6.06[A] ± 1.80	5.21[B] ± 1.93	5.95[A] ± 1.85	5.67[AB] ± 1.86
Overall liking*	5.88 ± 1.79	6.11 ± 1.70	6.22 ± 1.77	6.45 ± 1.48	6.61 ± 1.39	6.30 ± 1.67	6.14 ± 1.51	6.24 ± 1.78	5.90 ± 1.65

*No significant differences (α=0.05) based on a two-way ANOVA and Tukey's post-hoc test.
Means based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

from pale (chroma values: 31.9-34.7) to medium (chroma values: 47.6-51.6), slightly increased the salty taste liking scores. However, when color intensity increased from medium to intense (chroma values: 63.9-67.3), salty taste acceptance decreased. This effect was most pronounced at the medium spiciness level. Salty taste liking score increased from 5.96 ("pale" color) to 6.35 (medium color), and then decreased to 6.18 ("intense" color) in samples with a medium spiciness. Although not statistically significant, the highest salty taste liking was experienced at the "medium" color of high spiciness (6.41), while at the medium spiciness with "pale" color the lowest liking score (5.96) was observed. These results suggest that by changing color and spiciness intensity, the salty taste liking rating may switch from "neither like nor dislike", to "like slightly".
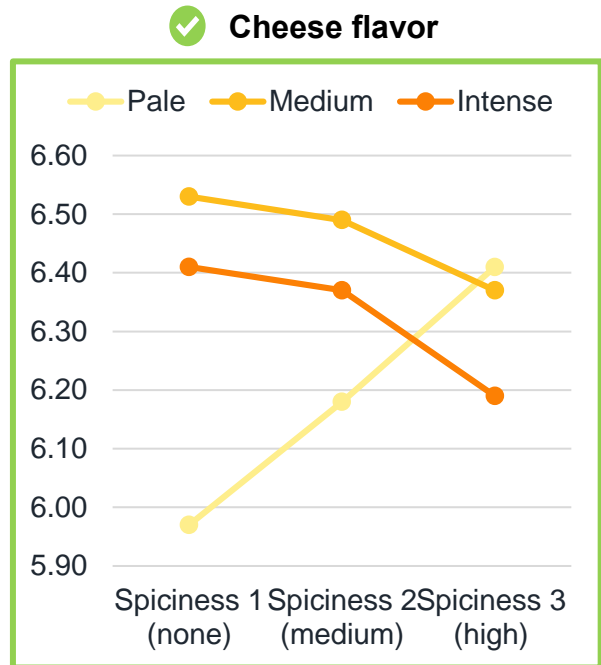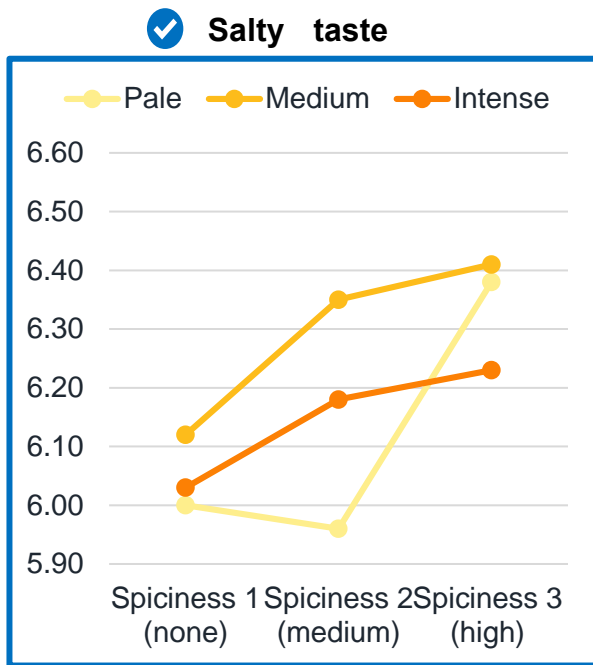

γMeans based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

Figure 4.5. Liking scoresγ of cheese dips with different color intensities

4.3.4. Trends of the effects of spiciness intensity on salty taste, cheese flavor and spiciness liking

Influenced by spiciness level, trends regarding salty taste, cheese flavor, and spiciness acceptance in cheese dips are shown in Figure 4.6. The upper left corner of Figure 4.6. shows the liking mean scores for salty taste. Even though it was not numerically significant, increasing spiciness from medium to high increased the salty taste liking score at all color levels. These findings suggest that spiciness level may influence the acceptance of saltiness. Results from this study are congruent with findings from Li et al. (2017), who investigated the role of capsaicin on the metabolic activity of the OFC region. Based on human and animal studies, Li et al. (2017) demonstrated that salt preference was related to the metabolic activity in the insula and the OFC. The OFC, also known as the secondary gustatory cortex, plays a key role on the hedonic responses to food (Wainford, 2017). Thus, the trend observed in this study may be explained by the fact that eating spicy foods increases the neural responses of NaCl in the OFC.

With respect to color, the upper right corner of Figure 4.6. shows the liking mean scores for the cheese flavor. In contrast to the salty taste liking, at the "medium" and "intense" colors, increasing spiciness level from "none" to "high", decreased the cheese flavor liking scores. Similar results of flavor and taste suppression as influenced by spiciness have been previously reported. Prescott and Stevenson (1995), who

^yMeans based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

Figure 4.6. Liking scores trends of cheese dips at different spiciness levels

Investigated whether capsaicin affected taste and flavor intensity, reported sweetness and flavor suppression when capsaicin was added to solutions. These authors suggested that the dominant pungency of capsaicin may have drawn subjects' attention to the spiciness sensation, suppressing the perception of less dominant components of the solution (Prescott & Stevenson 1995).

Lastly, as seen in Figure 4.6., increasing spiciness level from "none" to "medium" significantly ($p<0.05$) increased the spiciness liking score of cheese dips at all color levels. However, even though it was not significant, increasing from "medium" to "high" spiciness, decreased the spiciness liking score from the medium and intense colors. Overall, the "medium" spiciness treatments elicited the highest spiciness liking scores. By varying spiciness and color intensity, the spiciness liking of cheese dips significantly increased (by one point) from the "none" spiciness at the "pale" color treatment, to the "medium" spiciness at the "medium" color.

4.3.5. Trends of the effects of color and spiciness intensity on the overall liking of cheese dips

Figure 4.7. shows the overall liking score trends. The left area of Figure 4.7. shows the influence of spiciness level on the overall liking score. Increasing spiciness intensity from "none" to "medium" increased the overall liking score of the cheese dips at all color levels. Similar results were reported by Andersen et al. (2017), where subjects were asked to evaluate the sensory satisfaction of soups with and without cayenne. Interestingly, consumers reported to be significantly more satisfied during consumption of the soup with cayenne added compared to the soup without cayenne (Andersen, Byrne, Bredie, & Møller, 2017).

On the other hand, increasing color intensity from "pale" to "medium" increased the overall liking score of treatments at all spiciness levels. Even though results from this study were not statistically significant, trends suggest that there is a relationship between color intensity, spiciness (capsaicin), and the overall acceptability of cheese dips.
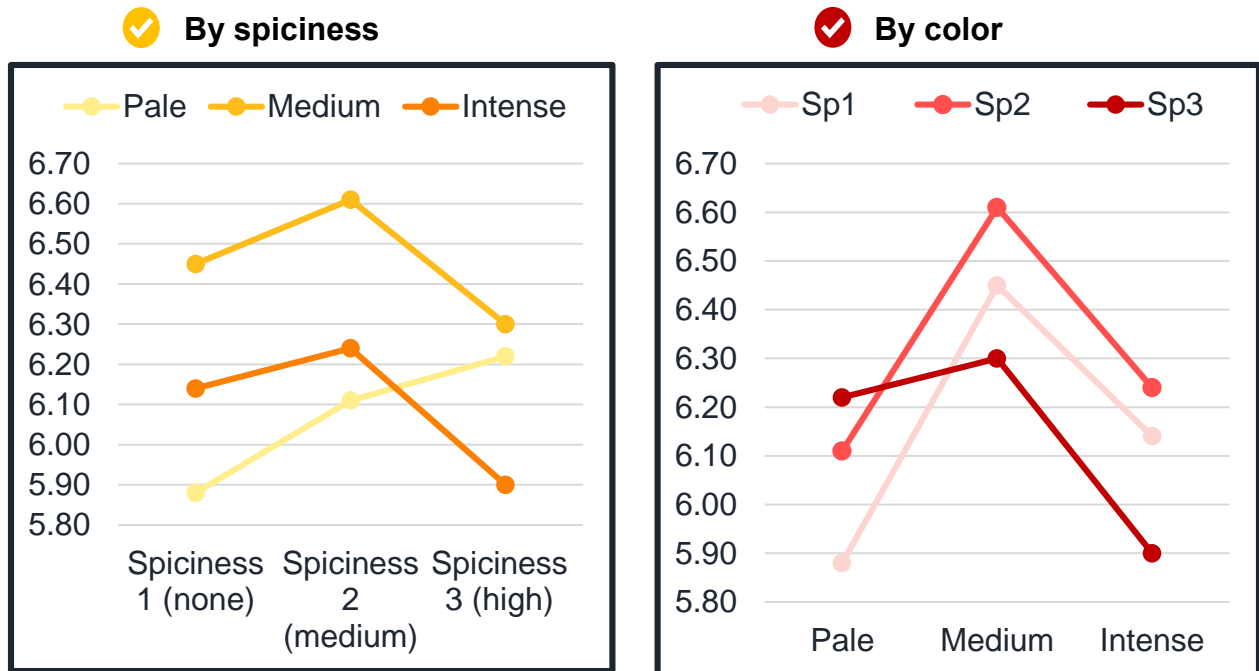
^γMeans based on a 9-point hedonic scale. (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).
*Sp: Spiciness

Figure 4.7. Overall liking scores trends as influenced by color and spiciness level

4.3.6. Influence of color and spiciness intensity on the salty taste intensity perception

A JAR (Just-About-Right) scale was used to measure the perceived intensity of the attributes in relationship to consumers' ideal intensity level. Frequencies of consumers' satisfaction towards salty taste intensity as influenced by spiciness level and

color intensity are shown in Table 4.11. JAR data showed similar trends found for the salty taste hedonic rating.

Table 4.11. Overall frequencies (%) of consumers' satisfaction towards salty taste intensity as influenced by spiciness level and color intensity

Spiciness	-	Color	-	% Not salty enough	%JAR	% Too salty
Spiciness 1		Pale		26.6	57.0	16.5
		Medium		20.3	55.7	24.1
		Strong		27.8	51.9	20.3
Spiciness 2		Pale		24.1	63.3	12.7
		Medium		17.7	69.6	12.7
		Strong		21.5	63.3	15.2
Spiciness 3		Pale		20.3	68.4	11.4
		Medium		16.5	72.2	11.4
		Strong		25.3	60.8	13.9

Effects of spiciness on salty taste intensity satisfaction are shown in Figure 4.8. Switching the spiciness level from "none" to "medium" increased salty taste JAR scores at all color levels. Also, for the "pale" and "medium" colors, increasing spiciness from "medium" to "high", increased salty taste intensity satisfaction. The increase of the salty taste intensity satisfaction was associated with a decrease of the not-salty-enough frequencies (Figure 4.8. on the left). These results indicate that increasing spiciness level generally increased saltiness intensity satisfaction. Similarly, Narukawa et al. (2011),

reported that a significantly higher number of subjects perceived a salted solution with capsaicin to be saltier than a solution with no capsaicin added. Findings from this study can be explained by the fact that when capsaicin is combined with NaCl, intensity-dependent metabolic changes elicited by NaCl are enhanced in the brain (Li et al. 2017).

With the highest frequency (72.2%) of consumers indicating that the salty taste of the cheese dip was just-about-right, the peak saltiness intensity was perceived at the "medium" color with "high" spiciness level. On the other hand, the lowest JAR frequency (51.9%) was observed at the "intense" color level with "none" spiciness. The change in JAR frequencies (from 51.9% to 72.2%) shows a 39 percent increase in the JAR frequency. According to the ASTM, if a products' attribute is perceived by more than 70 percent of consumers as JAR, no further optimization of the attribute needs to be performed (Rothman & Parker, 2009). This indicates that by combining color intensity and spiciness level, salty taste intensity of a reduced-sodium cheese dip was potentially optimized to an ideal point.

Increasing yellow/orange color intensity from "pale" to "medium" slightly increased consumers' salty taste intensity satisfaction at the "medium" and "high" spiciness level (Figure 4.9). However, when color intensity increased from "medium" to "intense", frequency of JAR ratings for the salty taste intensity decreased at all spiciness levels. As seen to the left in Figure 4.9 (not-salty-enough frequencies), the decrease of the JAR rating at the most intense color levels was associated with an increase of the not salty enough frequencies. These results indicate that even though cheese dips with a "medium"

color intensity were generally perceived as saltier, salty taste intensity perception decreased when color level was "intense"
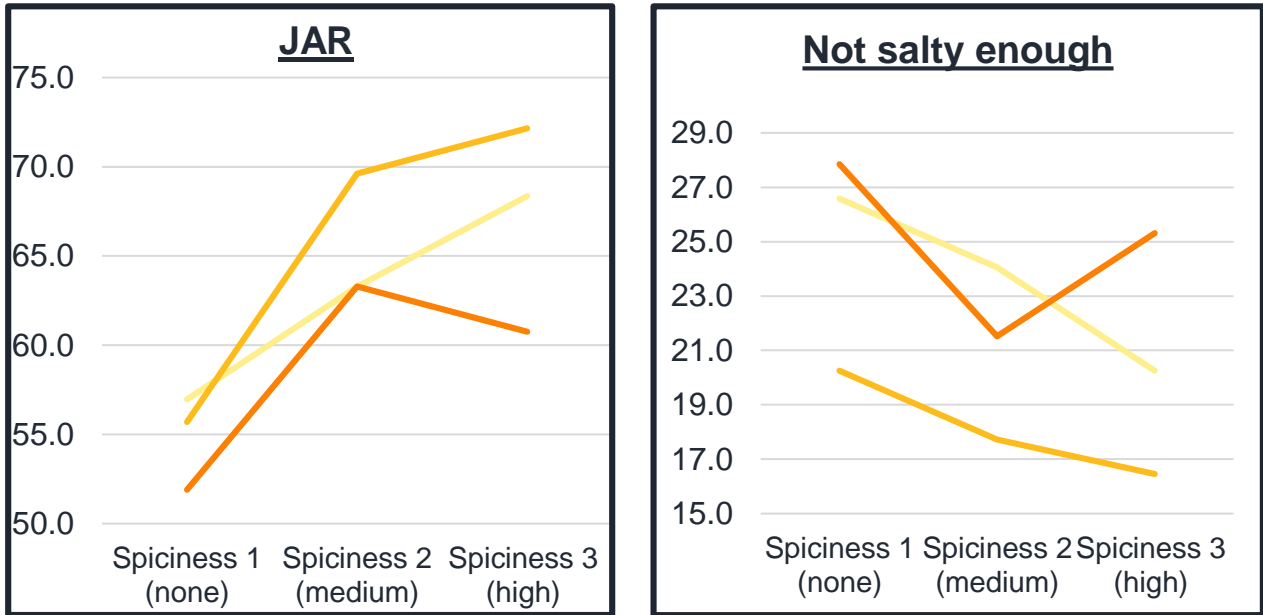

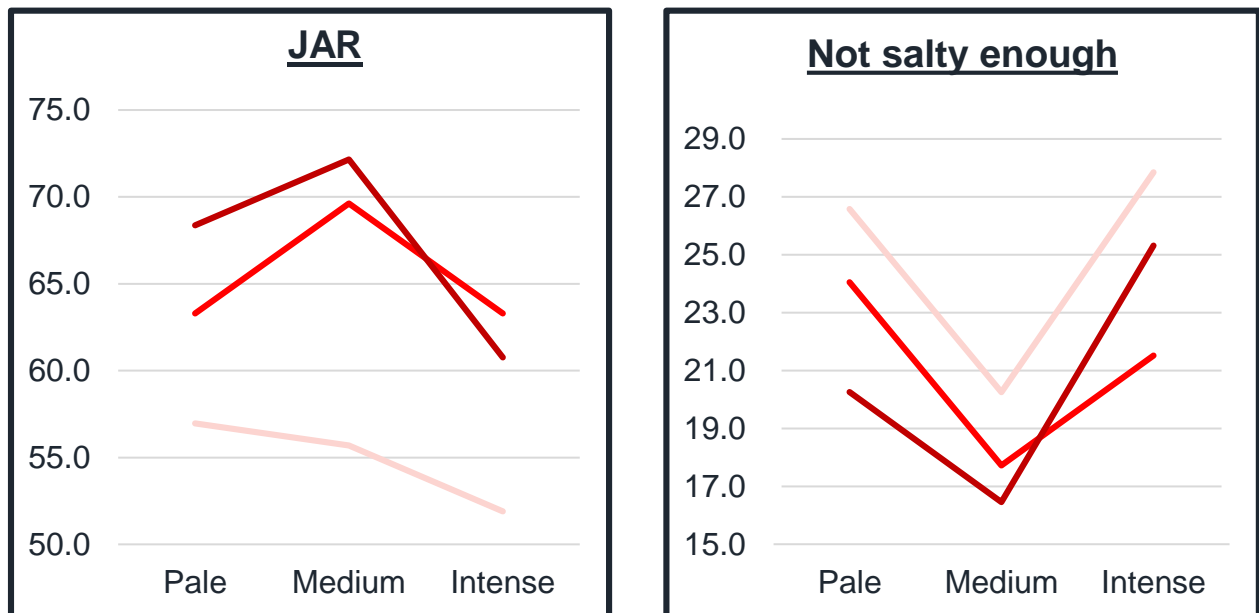Figure 4.8. Saltiness intensity trends as influenced by spiciness level

Figure 4.9. Saltiness intensity trends as influenced by color intensity

These effects of color intensity on salty taste intensity satisfaction can be explained by the assimilation/contrast expectancy disconfirmation model. As seen in Figure 4.10., congruently with study 1, increasing yellow/orange color intensity of cheese dips, increased the expected salty taste intensity of the product. By looking at consumers' salty taste intensity expectations vs. actual perception, it can be noticed that assimilation effects occurred for the "medium" color treatments as salty taste intensity perception increased from "pale" to "medium". However, when the level of discrepancy was too high, a contrast effect caused a decrease of the saltiness intensity satisfaction. Assimilation/contrast models have been previously reported on research investigating the influence of visual cues on perception (Cardello, 1994). For example, Cardello and Sawyer (1992) observed that when expectations for bitter taste where slightly low, consumers perceived the product as less bitter than the baseline. However, when the expectancy disconfirmation was too high, consumers experienced a higher bitterness from the product.

Meeting consumer's salty taste expectations is critical for product acceptance. As seen in Figure 4.11., mean-drop of the overall liking score was directly associated with a not-salty-enough sensory perception. Treatments with "intense" colors at all spiciness level and the "pale" cheese dip of the "none" spiciness level presented relevant and concerning overall liking mean drops between -1.55 and -2.1. This indicates that treatments that elicited the highest expectancy disconfirmation, affected the overall liking score negatively the most. Contrast effects have been previously found to negatively influence the overall liking of products when salty taste was not as expected (Yeomans et al., 2008).
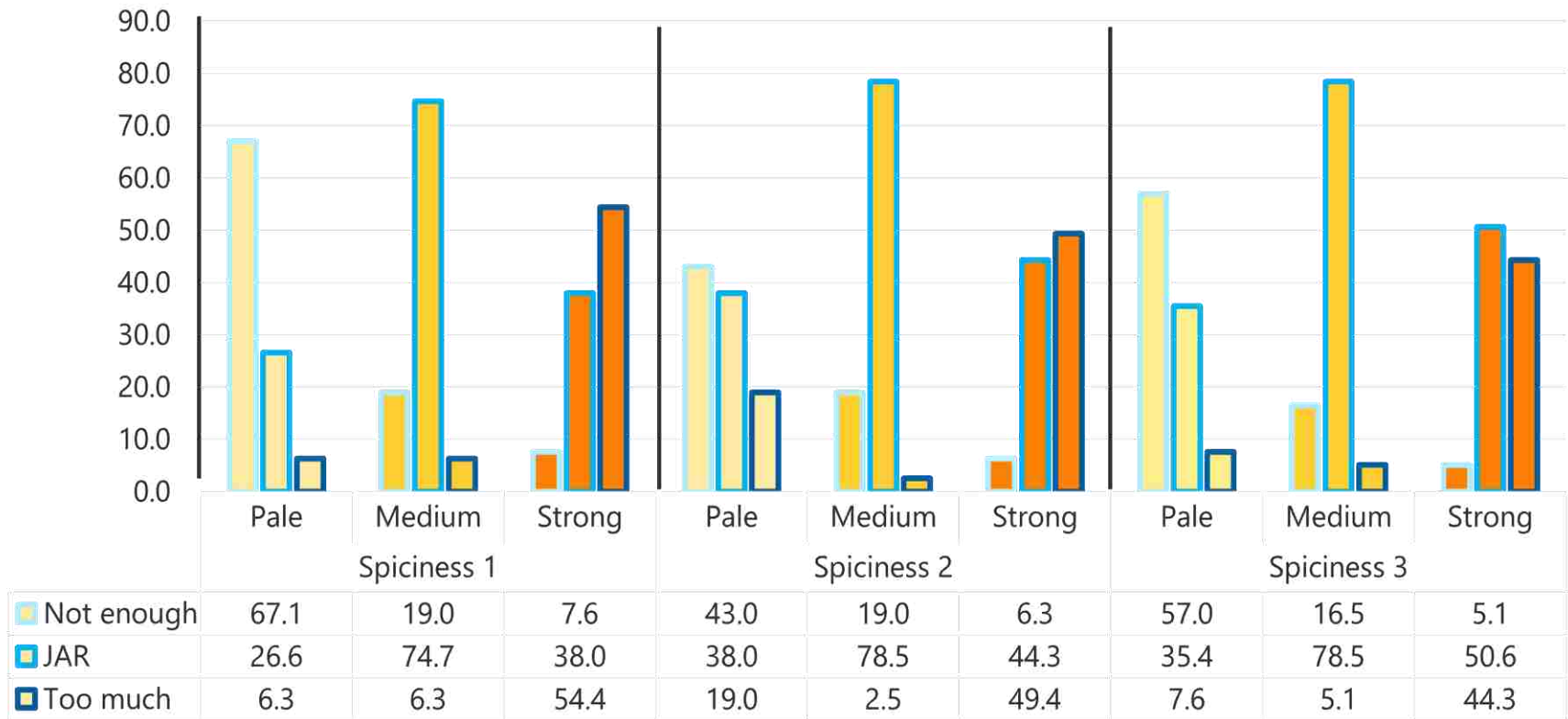
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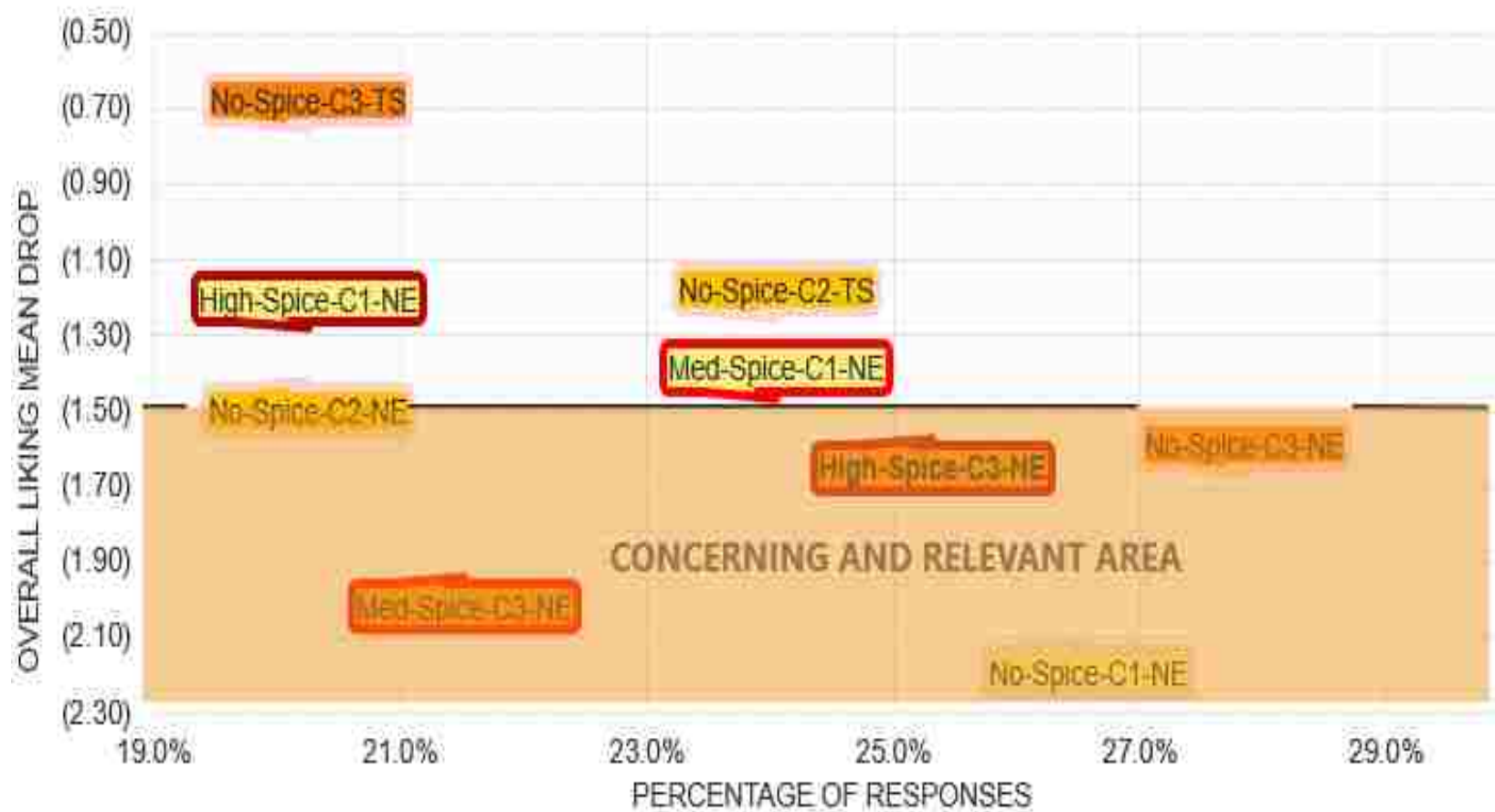| | Spiciness 1 | | | Spiciness 2 | | | Spiciness 3 | | |
	Pale	Medium	Strong	Pale	Medium	Strong	Pale	Medium	Strong
Not enough	67.1	19.0	7.6	43.0	19.0	6.3	57.0	16.5	5.1
JAR	26.6	74.7	38.0	38.0	78.5	44.3	35.4	78.5	50.6
Too much	6.3	6.3	54.4	19.0	2.5	49.4	7.6	5.1	44.3

Figure 4.10. Overall frequencies (%) of consumers' satisfaction towards the salty taste expectation

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*C1: Pale color, C2: Medium color, C3: Intense color, NE: Not-salty-enough, TS: Too-salty

Figure 4.11.–Mean drop of the overall liking score when salty taste was not ideal (too weak (TW)/too strong (TS)

4.3.7. Effects of color and spiciness intensity on the purchase intent of cheese dips

To evaluate consumers' willingness to purchase cheese dips after product tasting a binomial scale (yes/no) was used. The purchase intent scores of the treatments were consistent with findings from hedonic and JAR evaluations. Overall, for the "medium" and "intense" colors, people were more willing to buy cheese dips with a "medium" spiciness level. Cheese dips with a "medium" color and spiciness elicited the highest purchase intent frequency (68%). On the contrary, consumers were less willing to purchase cheese dips with an "intense" color and spiciness after tasting these dips. These results indicate that by optimizing color and spiciness intensity, consumer willingness to purchase cheese dips containing 33% less sodium than commercial brands increased by 54.4% (from 44.3% to 68.4%)

Table 4.12. Percentage of consumers that indicated a positive purchase intent

Spiciness Level	Color	%
Spiciness 1	Pale	49.4
	Medium	45.6
	Strong	51.9
Spiciness 2	Pale	49.4
	Medium	68.4
	Strong	57.0
Spiciness 3	Pale	55.7
	Medium	57.0
	Strong	44.3

4.4. Summary of results and conclusion

Expectancy disconfirmation driven by color intensity caused an assimilation/contrast effect in the perceived intensity of salty taste. Generally, increasing color intensity from pale to medium, increased the perceived saltiness of cheese dips. However, when a high discrepancy between expectations and actual taste was experienced at the most intense color, the perceived salty taste intensity decreased at all spiciness levels. On the other hand, increasing spiciness intensity generally increased the ideal (JAR) salty taste of cheese dips. Overall, by combining color intensity and spiciness level, the salty taste intensity perception of a cheese dip containing 33% less sodium than commercial brands was optimized to an ideal level. Also, by optimizing both conditions (color and spiciness), consumers' willingness to purchase cheese dips increased by 54.4%.

This study demonstrated that saltiness perception and acceptability of reduced-sodium cheese dips can be enhanced by using the multisensory approach, specifically, spiciness and color intensity. Findings from this research are beneficial for the food industry as opportunities to reduce salt in products without affecting the sensory perception were identified.

4.5. References

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CHAPTER 5. SUMMARY AND CONCLUSIONS

Reducing dietary sodium consumption has a direct positive impact on consumers' health. The majority of sodium intake is associated with processed foods. Thus, the food industry has been encouraged to reduce the amount of sodium in products. However, sodium reduction is a challenging task, as salt plays a key role in the functionality and palatability of foods. Therefore, there is a need to develop feasible strategies to reduce sodium in products without affecting the sensory qualities and acceptability of foods. This study was conducted to evaluate the viability of using color and spiciness as a strategy to increase the saltiness intensity perception, liking, and willingness to purchase a cheese dip with 33% less sodium than commercial products.

The findings from study one revealed that color and gender had a significant effect on salty taste expectations, visual liking, and purchase intent. Overall, increasing yellow/orange color intensity of cheese dips increased salty taste intensity expectations. However, females expected samples with higher color intensity to be saltier than males. For both females and males, increasing color intensity from "pale" to 'medium" increased hedonic responses, while more intense colors elicited lower salty taste liking scores. Yet, males tend to give higher salty taste liking ratings, particularly for the more intense colors, compared to females. Interestingly, females were shown to have the tendency to penalize the overall liking of the cheese dips, more than males, when the color and salty taste were not ideal. In terms of purchase intent, males were found to be more willing to purchase cheese dips with higher color intensities.

Results in study two suggested that both color intensity and spiciness level had an effect on the salty taste intensity perception and overall acceptability of reduced-sodium

cheese dips. Color intensity had a positive or negative effect on the salty taste intensity perception and hedonic ratings depending on the perceived expectancy incongruence. When the discrepancy between actual taste and expectations was small, at the medium color, salty taste intensity perception increased. However, when a high expectancy disconfirmation was experienced at the most intense color, saltiness intensity perception and liking of cheese dips decreased. On the other hand, increasing spiciness level, with cayenne, was shown to generally increase salty taste perception and liking. Overall, this study demonstrated that it is possible to achieve an ideal salty taste and increase the purchase intent of a reduced-sodium product by using the multisensory approach, specifically color intensity and spiciness level.

APPENDIX. LSU AGCENTER INSTITUTIONAL REVIEW BOARD (IRB) EXEMPTION FROM INSTITUTIONAL OVERSIGHT

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

VITA

Valentina Rosasco Silva was born in Cali, Colombia. She received her Bachelor of Science degree in Gastronomy from Universidad de La Sabana, Colombia. Prior to entering to the Food Science and Technology M.Sc. program at Louisiana State University, she spent 6 months working in the Sensory Sciences Lab of LSU doing research in Sensory and Consumer Sciences. During her graduate studies, she worked as an R&D scientist and Food Lab Manager at the LSU AgCenter Food Incubator. She expects to graduate with her master's degree in August 2018, after which she plans to pursue a career as a R&D/ Sensory Scientist.