Consumer sensory perception and liking of sodium-reduced food products

by

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ABSTRACT

Interest in the development of sodium-reduced processed foods has increased in recent years as the majority of dietary sodium in many industrialized countries comes from processed foods. The objectives of this research were to compare consumer sensory perception and liking between commercially available regular and sodium-reduced processed foods and to understand consumer heterogeneity in response to sodium reduction in processed foods, a topic not thoroughly explored in the literature.

Comparisons of static sensory attribute profiles and overall liking between regular and sodium-reduced foods were performed in the consumer panel (n=100) of the first study. Additionally, the influence of taste sensitivity and consumption frequency of dietary sodium sources (DSS) on consumer sensory perception were investigated to understand the heterogeneity of consumer perception. Four pairs of regular and sodium-reduced products (potato chips, pickles, cooked ham, chicken noodle soup) were evaluated for overall liking, Just-About-Right (JAR) saltiness and Rate-All-That-Apply (RATA) sensory profiles. In the second consumer study (n=20), temporal sensory profiles of regular and sodium-reduced foods were compared across 4 food item pairs (potato chips, canned corn, cooked ham and cream of mushroom soup) and between the temporal methods of Temporal Dominance of Sensation (TDS) and Temporal Check-All-That-Apply (TCATA), with additional multi-intake evaluations for chips and soup and evaluation by modality for ham. The influence of companion foods on consumer perception and liking of a regular and sodium-reduced foods was examined in the third study. Three consumer panels evaluated three food pairs; salsa with corn chips (n=98), ketchup with tater tots (n=100) and soy sauce with cooked rice (n=98). For each panel, consumers evaluated overall liking and RATA sensory profiles of 5 samples; the regular and sodium-reduced foods alone (corn chips, ketchup or soy sauce), the companion food alone and food pairs of the regular and sodium-reduced foods each with the companion food.

Overall, sodium reduction influenced consumer sensory perception and liking differently across food products and sensory methods. For single foods, regular and sodium-reduced products differed in static and temporal sensory profiles of not only salty taste but also other sensory attributes. The perceptible sensory differences between regular and sodium-reduced foods were acceptable to consumers for potato chips, cooked ham, corn chips and soy sauce. However, when consumed with companion foods there were limited sensory attribute differences between regular and sodium-reduced foods; only salty taste for the corn chips, salty and sweet tastes for soy sauce, but no significant differences for ketchup. The presence of the companion food reduced consumer ability to discriminate sensory attributes between regular and sodium-reduced products and changed the product sensory profiles and liking. Consumer heterogeneity in response to sodium reduction in processed foods was observed, confirming the food industry challenge to please every consumer with a single formulation. Consumption frequency of dietary sodium sources (DSS) influenced consumer sensory perception and liking. The 3-point RATA scale is an appropriate tool for static sensory profiling of regular and sodium-reduced food products. TDS profiles highlighted more product pair differences than TCATA profiles; TCATA profiles were more consistent across intakes. Ham evaluation by modality provided less detailed description of TDS profiles and identified more product pair differences in TCATA profiles. Results of the three studies of product pairs and sensory temporal methods are useful to generalize study findings and provide a guide for future application of study methods to develop sodium-reduced foods acceptable to targeted consumer segments.

PREFACE

This thesis is an original work by Ha T. T. Nguyen.

A version of Chapter 3 of this thesis has been accepted for publication as Nguyen, H., & Wismer, W. V. (2019). A comparison of sensory attribute profiles and liking between regular and sodium-reduced food products. *Food Research International*. https://doi.org/10.1016/j.foodres.2019.05.037. A version of Chapter 4 has been submitted to *Food Quality and Preference* as Nguyen, H., & Wismer, W. V. Temporal sensory profiles of regular and sodium-reduced foods elicited by Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA). A version of Chapter 5 has been submitted to *Journal of Food Science* as Nguyen, H., & Wismer, W. V. The Influence of Companion Foods on Sensory Perception and Liking of Regular and Sodium-Reduced Foods. An extended version of the narrative review in Appendix 1 will be submitted for publication to *Food Quality and Preference* as Nguyen, H., & Wismer, W. V. The influence of extrinsic product attributes on consumer sensory perception, preference and choice of sodium-reduced foods.

I designed and performed all studies (Chapter 2, 3 and 4) and drafted the manuscripts under the supervision and revision of Dr. Wendy V. Wismer. Financial support for this thesis was provided by a scholarship for Ha Nguyen from the Vietnam International Education Cooperation Department (VIED); the study described in chapter 4 was supported by a grant from the Alberta Livestock and Meat Agency (ALMA).

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ABBREVIATIONS

AML: Ascending Method of Limits

ANOVA: Analysis of variance

CATA: Check-All-That-Apply

CLT: Central-Location-Test

DSS: Dietary sodium sources -

FFQ: Food frequency questionnaire

FOP: Front-Of-Pack

FP: Flash Profile

HCPC: Hierarchical Clustering on Principal Components

HSD: honestly significant difference

HUT: Home-Use-Test

JAR: Just-About-Right

KCl: potassium chloride

MSG: monosodium glutamate

PCA: Principle Component Analysis

PROP: 6-n-propylthiouracil

QDA: Quantitative Descriptive Analysis

RATA: Rate-All-That-Apply

RDA: Ranking Descriptive Analysis

TCATA: Temporal Check-All-That-Apply

TDS: Temporal Dominance of Sensations

TI: Time Intensity

Chapter 1. Literature review and research objectives

1.1. Introduction

Sodium, an essential nutrient for humans, occurs naturally in foods and is added to foods during cooking, processing and serving as sodium chloride (salt) and food additives. Global dietary sodium intake is consistently higher than that recommended by the World Health Organization (Health Canada, 2018a; Powles et al., 2013); average daily sodium intake is estimated at 2760 mg for Canadians (Health Canada, 2018a), which is higher than the established goal of 2300 mg per day as recommended by the World Health Organization (World Health Organization, 2014). Although recent studies report conflicting evidence on the association between sodium reduction and health problems (Graudal & Jürgens, 2018; Mente et al., 2018), there is strong evidence that excessive dietary sodium intake results in negative health consequences such as hypertension, cardiovascular disease and stroke (Cappuccio, Beer, & Strazzullo, 2019; Petersen et al., 2019). Subsequently, an increasing number of countries around the world are developing guidelines, strategies and interventions to meet the target of 30% relative reduction in global population sodium intake towards the WHO-recommended level of less than 2 g per day by 2025 (Trieu et al., 2016, 2017, 2015; World Health Organization, 2006).

As in most industrialized countries, the majority of sodium in the typical Canadian diet comes from processed or food service food products, such as bakery products, mixed dishes, processed meats, cheeses, soups, sauces and condiments (Fischer, Vigneault, Huang, Arvaniti, & Roach, 2009; Health Canada, 2018a; World Health Organization, 2016). Successful sodium intake reduction requires both sodium reduction in processed foods and a change in consumer behaviors (Arcand et al., 2016; Sodium Working Group Canada, 2010). Food product reformulation is identified by the WHO (World Health Organization, 2016) as one of the key strategies for global dietary sodium reduction. Canada and many other countries have established targets for the food industry to reduce sodium content in food products (Bureau of Nutritional Sciences, 2012; Webster, Trieu, Dunford, & Hawkes, 2014).

A range of strategies to develop sodium-reduced processed foods has been applied (Inguglia, Zhang, Tiwari, Kerry, & Burgess, 2017; Silow, Axel, Zannini, & Arendt, 2016); however, success is limited as salt reduction leads to changes in the sensory quality of the product, an important contributor to consumer preference and satisfaction with foods (Inguglia et al., 2017; Israr, Rakha, Sohail, Rashid, & Shehzad, 2016; Liem, Miremadi, & Keast, 2011). A 2017 evaluation of Health Canada's 2012 food industry voluntary sodium reduction targets revealed that 48% of food categories did not make any meaningful progress toward sodium reduction while the sodium levels of foods in several categories increased (Bureau of Nutritional Sciences, 2012; Health Canada, 2018). Therefore, the food industry needs to continue efforts to reduce sodium in food products (Arcand et al., 2016). Knowledge of differences in sensory perception and consumer liking between regular and sodium-reduced food formulations will aid food industry initiatives to successfully develop sodium-reduced foods acceptable to consumers.

Consumer perception, behavior and food choice are influenced by many interacting factors, including intrinsic and extrinsic product attributes, consumer attributes and contextual attributes (Appendix 1; Köster & Mojet, 2018). Although sensory perception is a key driver for consumer preference (De Pelsmaeker, Schouteten, Lagast, Dewettinck, & Gellynck, 2017; Jaeger, 2006), consumer preference and choice of sodium-reduced foods may be influenced by extrinsic product attributes, i.e. labelling (Appendix 1), brand (Ares et al., 2018; Hubbard, Jervis, & Drake, 2016; Lee, Han, Caputo, & Nayga, 2015; McLean, Hoek, & Hedderley, 2012; Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Adasme-Berríos, 2019; Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Lobos, 2019), price (Hubbard et al., 2016; Lee et al., 2015; Shan et al., 2017) and country of origin (domestic vs. imported) (Lee et al., 2015). Recently, an increasing number of studies have been performed to explore the influence of Front-Of-Pack (FOP) labelling on consumer sensory perception, preference and choice of sodium-reduced foods; however, the influences are diverse across food products and types of FOP labelling (i.e. de Almeida et al., 2017; de Andrade et al., 2018; Liem, Miremadi, Zandstra, & Keast, 2012; Sukkwai et al., 2018; Tórtora, Machín, & Ares, 2019; Zandstra, Willems, & Lion, 2018). Several consumer attributes such as PROP sensitivity, the interest in sodium reduction and health, health status, sodium intake and usual consumption of dietary sodium sources, are associated with sensory perception and liking for salt taste (Hayes, Sullivan, & Duffy, 2010; McLean, 2014; Zandstra, Lion, & Newson, 2016), liking or choice of sodium-reduced products (Antúnez, Giménez, Alcaire, Vidal, & Ares, 2019; Bobowski, Rendahl, & Vickers, 2015; Liem, Toraman Aydin, & Zandstra, 2012; Vázquez, Curia, & Hough, 2009; Zandstra et al., 2018). Among significant dietary sodium sources, many companion foods are consumed together in context of a snack or meal, such as mayonnaise with bread, salsa with corn chips, or ketchup with French fries. Sensory studies on these products are best performed on food pairings or within meal contexts (Lahne, 2018).

Recent published reviews have focused on food reformulation strategies for sodium reduction and the influence of sodium reduction on product sensory perception and consumer preference (Allison & Fouladkhah, 2018; Doyle & Glass, 2010; Fouladkhah, Berlin, & Bruntz, 2015; Hoppu et al., 2017; Inguglia, Zhang, Tiwari, Kerry, & Burgess, 2017; Israr, Rakha, Sohail, Rashid, & Shehzad, 2016; Jaenke, Barzi, McMahon, Webster, & Brimblecombe, 2017; Kloss, Meyer, Graeve, & Vetter, 2015; Lopes, Cavaleiro, & Ramos, 2017; Silow, Axel, Zannini, & Arendt, 2016). The following review sections (Section 1.2 – 1.5) summarize the roles of sodium in processed foods, food reformulation strategies for sodium reduction and changes in sensory quality and consumer preference due to sodium reduction in food products.

1.2. Roles of sodium in processed foods

Sodium is an essential nutrient; it maintains fluid balance and blood pressure, muscle contraction, nerve cell transmission, and most cell functions (Durack, Alonso-Gomez, & Wilkinson, 2008). Sodium occurs naturally in foods or is added to foods during cooking, processing or serving. Among food additives containing sodium, salt (sodium chloride) is the main sodium source in high sodium processed foods. Salt plays an important positive role in food flavor and texture. Salt is the saltiest tasting sodium compound (McCaughey, 2007), and is added to many foods to produce a salty taste. Salty taste perception is influenced by the type of food matrix and interactions with other taste compounds, i.e. salt decreases bitterness and increases sweetness (Busch, Yong, & Goh, 2013; Keast & Breslin, 2003; Liem, Miremadi, & Keast, 2011). Thus, in breads and bakery products, where salty is not a dominant flavor, sodium is responsible for overall flavor impression (Silow, Axel, et al., 2016).

Salt has important antimicrobial and functional roles in food processing and storage. Historically, salt has been used at relatively high concentrations to limit the growth of pathogens and spoilage microorganisms in meat, fish, vegetables, eggs and some fruits (Doyle & Glass, 2010). Functional roles of sodium are important to product quality and sensory characteristics of breads and bakery products, processed meats, cheeses and other fermented foods (Doyle & Glass, 2010; Inguglia et al., 2017; Silow, Axel, et al., 2016). Salt affects growth and metabolic activities of cheese starter cultures and yeast in bread doughs, thus influencing both flavor and texture of fermented products. Salt delays the hydration of gluten protein and the development of the dough gluten matrix, which allows small air bubbles to be evenly dispersed throughout the final product (Silow, Axel, et al., 2016). Salt generally presents in meat products at 1.5 – 2% w/w because of its additional functional roles; it activates extraction of meat proteins, solubilizes proteins, and enhances the hydration of protein and the bindings of protein and protein, protein and fat, therefore stabilizes emulsions of ground meat mixed with fat, resulting in a decrease in fluid loss during cooking and an increase in juiciness (Inguglia et al., 2017). Salt improves cheese texture through its influence on hydration of milk proteins and emulsification of fats (Doyle & Glass, 2010). The present of salt in baked products also enhances the dark color of Maillard reactions by improving mobility of reactants.

1.3. Food reformulation strategies for sodium reduction

Sodium reduction may affect processing conditions, i.e. moisture levels, fat content, pH, starter cultures, fermentation temperature, additives, resulting in changes to product quality and shelf-life (Liem et al., 2011). Therefore, modification of ingredients and processing conditions is needed to develop sodium-reduced foods. A range of strategies have been developed and applied to reformulation of food products to reduce sodium content, including simple and gradual reduction, salt replacement, flavor compensation with flavor enhancers through taste-taste and taste-odor interactions, taste contrast by inhomogeneous spatial distribution of salt and the use of encapsulated salt, improvement of salt diffusion by modification of the food matrix, changes in the physical form of salt and novel technologies such as high pressure or ultrasound (Hoppu et al., 2017; Inguglia et al., 2017; Israr et al., 2016). Food reformulation has been applied to a range of food products, including breads and bakery products, cheeses and spreads, processed meats, soups and miscellaneous products, and sodium reduction levels have been achieved differently across product types (Jaenke et al., 2017).

1.4. Sensory perception of sodium-reduced foods

1.4.1. Salty taste perception and static sensory profiles

A body of studies in the literature compare salty taste perception and/or static sensory profiles (uni-point evaluation of sensory attributes) among food product research samples with tailored sodium levels; traditional descriptive sensory analysis with trained panelists, i.e. Quantitative

Descriptive Analysis (QDA), has been used in most studies to evaluate the sensory attributes of the products. Regular and sodium-reduced formulations have also been differentiated by descriptive consumer methods, i.e. Free Listing for dry fermented sausages (Dos Santos et al., 2015) and cheese (Costa et al., 2018), Check-All-That-Apply (CATA) for bread (Antúnez, Giménez, Alcaire, Vidal, & Ares, 2017; Antúnez, Giménez, & Ares, 2016), dry fermented sausages (Dos Santos et al., 2015) and cooked ham (Henrique, Deliza, & Rosenthal, 2015), Flash Profile (FP) for puff pastry (Silow, Zannini, Axel, Lynch, & Arendt, 2016), and Ranking Descriptive Analysis (RDA) for white pudding (Fellendorf, O'Sullivan, & Kerry, 2015, 2016) and cured meat products (Delgado-Pando et al., 2018).

Sodium reduction affects not only salty taste perception but also other sensory attributes, including flavor, texture and appearance (Inguglia et al., 2017; Israr et al., 2016). In addition to possible changes in processing conditions, multisensory interactions (taste-taste, taste-aroma) and changes in product structure due to sodium reduction also contribute to product sensory changes (Busch et al., 2013). Sensory attributes most affected by simple sodium reduction in meat products (i.e. sausages, bacon, ham, salami) were salty and texture attributes (noticeably *juiciness*) evaluated by trained panelists (i.e. Aaslyng, Vestergaard, & Koch, 2014) or untrained panelists (Delgado-Pando et al., 2018). Simple sodium reduction decreased salty, buttery and other flavors of Mozzarella cheese after 6 months of aging as evaluated by trained panelists (Ganesan, Brown, Irish, Brothersen, & McMahon, 2014). Taste contrast and the improvement of salt diffusion have been used to maintain salty taste perception in sodium-reduced foods, i.e. the use of inhomogeneous distribution of salt in bread (Stieger, Bult, Hamer, & Noort, 2009; Stieger & Van de Velde, 2013), encapsulated salt in bread (Noort, Bult, & Stieger, 2012), and smaller salt crystals in shoestring potatoes (Freire et al., 2015; Rodrigues, de Souza, Mendes, Nunes, & Pinheiro, 2016) and potato crisps (Rama et al., 2013).

Salt replacement is one of the most common strategies for manufacturers to reformulate food products. While sodium substitutes such as potassium, magnesium or calcium contribute a salty taste quality, they may also provide undesirable tastes such as bitter, metallic and astringent, which has limited their current use in food manufacturing (Sinopoli & Lawless, 2012; Stieger & Van de Velde, 2013). The intensity of bitter taste and associated off-flavors can be decreased by using bitter blockers or sweeteners such as thaumatin and sucrose and food grade acids can enhance saltiness of sodium (Liem et al., 2011). Bitter and sour tastes are reported as 'noticeably undesirable attributes' when sodium substitutes are incorporated into food products such as processed meats, cheeses, spreads, and breads (Ares et al., 2016; da Silva, de Souza, Pinheiro, Nunes, & Freire, 2014; de Souza et al., 2013; Paulsen, Nys, Kvarberg, & Hersleth, 2014; Rodrigues, Goncalves, Pereira, Carneiro, & Pinheiro, 2014; Ventanas, Puolanne, & Tuorila, 2010).

To offset sodium reduction, flavor compensation with the addition of flavors or flavor enhancers, such as herbs and spices, soy sauce, yeast extract or monosodium glutamate (MSG) might improve product sensory profiles. Umami taste of MSG, soy sauce and other compounds enhanced salty taste through the activation of receptors in mouth (Lopes et al., 2017). MSG was used for sodium-reduced spicy soups without changing salty taste perception (Jinap, Hajeb, Karim, Norliana, & Abdul-Kadir, 2016). Soy sauce has been used as a sodium replacer and flavor enhancer in a range of sodium-reduced foods, such as breads, sausages, soups and dressings (Cho Long, Soh Min, & Kwang-Ok, 2015; Kremer, Mojet, & Shimojo, 2009; Kremer, Shimojo, Holthuysen, Köster, & Mojet, 2013; McGough, Sato, Rankin, & Sindelar, 2012; Xin Wei Goh et al., 2011).

1.4.2. Temporal sensory profiles

By revealing sensory perception changes during food oral processing, temporal sensory methods are useful for development of sodium-reduced foods to understand the impact of reformulation for sodium reduction (Stieger & Van de Velde, 2013). An increasing number of studies have been published of the temporal sensory profiles of a range of sodium-reduced products (Antúnez, Giménez, Vidal, & Ares, 2018; Ares et al., 2016; da Silva et al., 2014; de Souza et al., 2013; Gonçalves et al., 2017; Lorido, Estévez, & Ventanas, 2018; Lorido, Hort, Estevez, & Ventanas, 2016; Paulsen et al., 2014; Rodrigues et al., 2016; Rodrigues, Goncalves, et al., 2014; Rodrigues, Junqueira, et al., 2014; Silva et al., 2018; Ventanas et al., 2010; Wendin, Langton, Caous, & Hall, 2000).

Among current temporal sensory profiling methods (Castura, 2018), Time Intensity (TI), Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA) have been applied to the evaluation of sodium-reduced products. TI with trained panelists enables temporal intensity measurement of one attribute at a time (Lee III & Pangborn, 1986); thus, it has been mainly used to compare temporal salty perception of research food samples with tailored levels of sodium and/or sodium replacers. Several studies also used TI for sensory profiling of sodium-reduced foods with a limited number of sensory attributes (Lorido et al., 2018; Ventanas et al., 2010). Changes in several product sensory attributes can be considered concurrently in TDS and TCATA by trained panelists or consumers. TDS was originally proposed as a multi-attribute temporal sensory method that scaled the intensities of a sequence of dominant attributes (Pineau et al., 2009). A variant of TDS (Pineau et al., 2012), in which the dominant attribute is selected without scaling its intensity, has been widely used. TCATA, a more recent temporal method, generates a continuous description of the sensory characteristics concurrently perceived in products (Ares et al., 2016; Castura, Antúnez, Giménez, & Ares, 2016).

TDS has been used in most studies for temporal profiling of sodium-reduced foods while TCATA were used only for bread samples of different levels of sodium replacement by potassium salt mix (Antúnez et al., 2018; Ares et al., 2016).

Temporal profiles of research samples with tailored levels of sodium reduction and/or replacement by sodium replacers/flavor enhancers may differ not only in salty taste but also other flavor and texture attributes; i.e. bitterness and pastiness of dry-cured loins with several levels of sodium and replacement by potassium evaluated by both TI and TDS (Lorido et al., 2018). Silva et al. (2018) observed that the addition of flavor enhancers, yeast and oregano in particular, increased salty intensity of sodium-reduced probiotic Prato cheese in static evaluation by QDA but not for temporal salty taste perception by TDS; the use of flavor enhancers also decreased bitter taste perception and allowed other flavors to be dominant. For the food products in which salty taste is strongly dominant over other attributes, it was possible to partly replace sodium with sodium replacers and/or flavor enhancers without changing the temporal sensory attribute profile, i.e. sodium-reduced margarine with the use of potassium chloride and MSG (Gonçalves et al., 2017).

1.5. Consumer liking of sodium-reduced foods

Perceived salty intensity is correlated with product liking (Hayes et al., 2010; Lucas, Riddell, Liem, Whitelock, & Keast, 2011); excessive sodium consumption is considered a salt addiction more than just a preference for salt taste (Soto-Escageda et al., 2016). The relationship between salty intensity and liking is described by an individual ‘optimum salt curve’, which identifies the most liking for a certain salt concentration in food (Zandstra, De Graaf, Mela, & Van Staveren, 2000; Zandstra et al., 2016).

The influence of salt reduction on consumer preference differs across product types; substantial sodium reduction can be achieved for breads and processed meats without changing consumer acceptability, up to approximately 40% in breads and 70% in processed meats while sodium reduction in other food categories is less conclusive (Jaenke et al., 2017). La Croix et al. (2015) reported that although consumers detected a difference in saltiness between regular and 30%-sodium-reduced breads, they had no preference between the samples. Sodium reduction from 2.5% w/w salt to 1.5% w/w salt in bacon and from 2.0% w/w salt to 1.2% w/w salt in cooked ham did not change consumer acceptability while consumers differentiated sensory properties between samples using RDA. Consumers detected sensory differences and decreased the acceptability with sodium reduction in cheese at low levels for some cases, i.e. 13% for cottage cheese (Drake, Lopetcharat, & Drake, 2011), but not for others, i.e. 25% for Edam cheese (Czarnacka-Szymani & Jezewska-Zychowicz, 2015). However, in addition to these findings summarized across panel participants, there is consumer heterogeneity in response to sodium reduction in foods, as observed by Antúnez, Giménez, Alcaire, Vidal, & Ares (2019) for liking of sodium-reduced breads, and Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Adasme-Berríos (2019) for purchase intention of sodium-reduced processed meats.

In most previous studies, consumer liking has been assessed by Central-Location-Test (CLT) with hedonic rating, particularly the 9-point hedonic scale. However, CLT may not reliably predict consumer liking of sodium-reduced foods in real consumption contexts, i.e. home, restautants. CLT and Home-Use-Test (HUT) provided different results of consumer perception (Boutrolle, Arranz, Rogeaux, & Delarue, 2005; Boutrolle, Delarue, Arranz, Rogeaux, & Köster, 2007). Willems et al. (2013) reported that liking scores were higher in HUT than CLT after repeated in-home consumption of sodium-reduced soups. Lucas et al. (2011) found that larger decreases of sodium content were achieved with minor decrease of liking of hash brown in a dining room environment than in a sensory lab (CLT).

1.6. Research objectives

Salt plays an important role in food sensory quality and safety via its salty taste, antimicrobial and functional properties. Food reformulation towards sodium reduction may change static and temporal sensory profiles, not only in salty taste perception but also other sensory attributes. Various strategies have been applied to a range of sodium-reduced foods. Sodium reduction is achieved at different levels between and within food categories. Sensory perception is an important factor of consumer preference, and the presence of FOP labelling can modify consumer perception and influence choice of sodium-reduced foods. Moreover, consumers may respond differently to sodium reduction in processed foods; their perception may be influenced by inter-individual differences. Knowledge of consumer sensory perception and liking of regular and sodium-reduced foods, and the consumer heterogeneity in response to sodium reduction in processed foods will be useful for successful development of sodium-reduced foods acceptable to targeted consumer segments.

Most previous sensory studies of sodium-reduced food products have evaluated static sensory perception and/or consumer liking of research samples with tailored sodium levels to guide development of sodium-reduced foods. Recently, an increasing number of studies have been published on temporal sensory profiles of research samples of sodium-reduced foods. Little is known about consumer sensory perception and liking of commercially available regular and sodium-reduced products, in which differences are minimized to maintain consumer acceptance, and the associations between inter-individual differences and consumer sensory perception of regular and sodium-reduced foods. Moreover, there have been no reports of sensory perception and consumer liking for sodium-reduced foods consumed with companion foods.

The overall objective of this research was to evaluate consumer sensory perception and liking in response to sodium reduction in processed foods. Three studies were performed with the following specific objectives.

Objectives:

Study 1 (Chapter 2):

(1) to compare sensory profiles and overall liking between regular and sodium-reduced formulations of processed food products that make substantial sodium contributions to the Canadian diet;

(2) to examine the influence of individual sensory acuity and consumption frequency of dietary sodium sources on sensory perception and liking of common regular and sodium-reduced food products available in the marketplace.

Study 2 (Chapter 3):

(3) to compare temporal sensory profiles between common salty food products available in the marketplace and their sodium-reduced counterparts;

(4) to compare Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA) sensory profiles of these products, including single versus multiple intakes and evaluation across modalities versus by modality.

Study 3 (Chapter 4):

(5) to compare sensory profiles and overall liking between regular and sodium-reduced foods consumed with or without companion foods;

(6) to examine changes in sensory profiles and overall liking when foods are consumed with companion foods.

Comparisons across products and methods can provide a guide for further applications of these study methods to other food products, and knowledge of consumer sensory perception and liking of commercially available regular and sodium-reduced products may aid development of sodium-reduced foods acceptable to targeted consumer segments.

1.7. References

Aaslyng, M. D., Vestergaard, C., & Koch, A. G. (2014). The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Science*, *96*(1), 47–55. https://doi.org/10.1016/j.meatsci.2013.06.004

Allison, A., & Fouladkhah, A. (2018). Adoptable interventions, human health, and food safety considerations for reducing sodium content of processed food products. *Foods*, *7*(2), 16. https://doi.org/10.3390/foods7020016

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2017). Consumer perception of salt-reduced breads: Comparison of single and two-bites evaluation. *Food Research International*, *100*(July), 254–259. https://doi.org/10.1016/j.foodres.2017.07.014

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2019). Consumers' heterogeneity towards salt reduction: Insights from a case study with white rice. *Food Research International*, *121*(March), 48–56. https://doi.org/10.1016/j.foodres.2019.03.007

Antúnez, L., Giménez, A., & Ares, G. (2016). A consumer-based approach to salt reduction: Case study with bread. *Food Research International*, *90*, 66–72. https://doi.org/10.1016/j.foodres.2016.10.015

Antúnez, L., Giménez, A., Vidal, L., & Ares, G. (2018). Partial replacement of NaCl with KCl in bread: Effect on sensory characteristics and consumer perception. *Journal of Sensory Studies*, *33*(5), 1–12. https://doi.org/10.1111/joss.12441

Arcand, J., Jefferson, K., Schermel, A., Shah, F., Trang, S., Kutlesa, D., … Abbe, M. R. L. (2016). Examination of food industry progress in reducing the sodium content of packaged foods in Canada : 2010 to 2013. *Appl. Physiol. Nutr. Metab.*, *41*(April), 1–7. https://doi.org/dx.doi.org/10.1139/apnm-2015-0617

Ares, G., Aschemann-Witzel, J., Curutchet, M. R., Antúnez, L., Machín, L., Vidal, L., & Giménez, A. (2018). Product reformulation in the context of nutritional warning labels:

Exploration of consumer preferences towards food concepts in three food categories. *Food Research International*, *107*, 669–674. https://doi.org/10.1016/j.foodres.2018.03.021

Ares, G., Castura, J. C., Antúnez, L., Vidal, L., Giménez, A., Coste, B., … Jaeger, S. R. (2016). Comparison of two TCATA variants for dynamic sensory characterization of food products. *Food Quality and Preference*, *54*, 160–172. https://doi.org/10.1016/j.foodqual.2016.07.006

Bobowski, N., Rendahl, A., & Vickers, Z. (2015). A longitudinal comparison of two salt reduction strategies: Acceptability of a low sodium food depends on the consumer. *Food Quality and Preference*, *40*(PB), 270–278. https://doi.org/10.1016/j.foodqual.2014.07.019

Boutrolle, I., Arranz, D., Rogeaux, M., & Delarue, J. (2005). Comparing central location test and home use test results: Application of a new criterion. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2005.03.015

Boutrolle, I., Delarue, J., Arranz, D., Rogeaux, M., & Köster, E. P. (2007). Central location test vs. home use test: Contrasting results depending on product type. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2006.06.003

Bureau of Nutritional Sciences. (2012). *Guidance for the food industry on reducing sodium in processed foods, Canada*. *World action on salt*. Retrieved from http://www.worldactiononsalt.com/docs/world/78296.pdf

Busch, J. L. H. C., Yong, F. Y. S., & Goh, S. M. (2013). Sodium reduction: Optimizing product composition and structure towards increasing saltiness perception. *Trends in Food Science and Technology*, *29*(1), 21–34. https://doi.org/10.1016/j.tifs.2012.08.005

Cappuccio, F. P., Beer, M., & Strazzullo, P. (2019). Population dietary salt reduction and the risk of cardiovascular disease. A scientific statement from the European Salt Action Network. *Nutrition, Metabolism and Cardiovascular Diseases*, *29*(2), 107–114. https://doi.org/10.1016/j.numecd.2018.11.010

Castura, J. C. (2018). Dynamics of consumer perception. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 1: New approaches to classic methods* (Vol. 1, pp. 211–240). Elsevier Ltd. https://doi.org/https://doi.org/10.1016/B978-0-08-102089-0.00009-1

Castura, J. C., Antúnez, L., Giménez, A., & Ares, G. (2016). Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Quality and Preference*, *47*, 79–90. https://doi.org/10.1016/j.foodqual.2015.06.017

Cho Long, L., Soh Min, L., & Kwang-Ok, K. (2015). Use of consumer acceptability as a tool to determine the level of sodium reduction: a case study on beef soup substituted with potassium chloride and soy-sauce odor. *Journal of Food Science*, *80*(11), S2570–S2577. https://doi.org/10.1111/1750-3841.13098

Costa, R. G. B., Alves, R. C., Cruz, A. G. da, Sobral, D., Teodoro, V. A. M., Costa Junior, L. C. G., … Miguel, E. M. (2018). Manufacture of reduced-sodium Coalho cheese by partial replacement of NaCl with KCl. *International Dairy Journal*, *87*, 37–43. https://doi.org/10.1016/j.idairyj.2018.07.012

Czarnacka-Szymani, J., & Jezewska-Zychowicz, M. (2015). Impact of nutritional information on consumers' acceptance of cheese with reduced sodium chloride content. *International Dairy Journal*, *40*, 47–53. https://doi.org/10.1016/j.idairyj.2014.08.017

da Silva, T. L. T., de Souza, V. R., Pinheiro, A. C. M., Nunes, C. A., & Freire, T. V. M. (2014). Equivalence salting and temporal dominance of sensations analysis for different sodium chloride substitutes in cream cheese. *International Journal of Dairy Technology*, *67*(1), 31–38. https://doi.org/10.1111/1471-0307.12100

de Almeida, M. A., Montes, N., Saldaña, E., Pinto, J., Contreras-Castillo, C. J., Montes Villanueva, N. D., … Contreras-Castillo, C. J. (2017). Are sensory attributes and acceptance influenced by nutritional and health claims of low-sodium salami? Preliminary study with Brazilian consumers. *Scientia Agropecuaria*, *8*(4), 389–399. https://doi.org/10.17268/sci.agropecu.2017.04.10

de Andrade, J. C., Nalério, E. S., Giongo, C., de Barcellos, M. D., Ares, G. G., Deliza, R., … Deliza, R. (2018). Consumer sensory and hedonic perception of sheep meat coppa under blind and informed conditions. *Meat Science*, *137*(May 2017), 201–210. https://doi.org/10.1016/j.meatsci.2017.11.026

De Pelsmaeker, S., Schouteten, J. J., Lagast, S., Dewettinck, K., & Gellynck, X. (2017). Is taste the key driver for consumer preference? A conjoint analysis study. *Food Quality and Preference*, *62*, 323–331. https://doi.org/10.1016/j.foodqual.2017.02.018

de Souza, V. R., Freire, T. V. M., Saraiva, C. G., de Deus Souza Carneiro, J., Pinheiro, A. C. M., & Nunes, C. A. (2013). Salt equivalence and temporal dominance of sensations of different sodium chloride substitutes in butter. *Journal of Dairy Research*, *80*(3), 319–325. https://doi.org/10.1017/S0022029913000204

Delgado-Pando, G., Fischer, E., Allen, P., Kerry, J. P., O'Sullivan, M. G., & Hamill, R. M. (2018). Salt content and minimum acceptable levels in whole-muscle cured meat products. *Meat Science*, *139*(January), 179–186. https://doi.org/10.1016/j.meatsci.2018.01.025

Dos Santos, B. A., Bastianello Campagnol, P. C., da Cruz, A. G., Galvão, M. T. E. L., Monteiro, R. A., Wagner, R., & Pollonio, M. A. R. (2015). Check all that apply and free listing to describe the sensory characteristics of low sodium dry fermented sausages: Comparison with trained panel. *Food Research International*, *76*(Part 3), 725–734. https://doi.org/10.1016/j.foodres.2015.06.035

Doyle, M. E., & Glass, K. A. (2010). Sodium reduction and its effect on food safety, food quality, and human health. *Comprehensive Reviews in Food Science and Food Safety*, *9*(1), 44–56. https://doi.org/10.1111/j.1541-4337.2009.00096.x

Drake, S. L., Lopetcharat, K., & Drake, M. A. (2011). Salty taste in dairy foods: Can we reduce the salt? *Journal of Dairy Science*, *94*(2), 636–645. https://doi.org/10.3168/jds.2010-3509

Durack, E., Alonso-Gomez, M., & Wilkinson, M. (2008). Salt: A review of its role in food science and public health. *Current Nutrition & Food Science*, *4*(4), 290–297. https://doi.org/10.2174/157340108786263702

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding. *Meat Science*, *103*, 75–82. https://doi.org/10.1016/j.meatsci.2014.12.010

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016). Effect of using ingredient replacers on the physicochemical properties and sensory quality of low-salt and low-fat white puddings.

European Food Research and Technology, *242*(12), 2105–2118. https://doi.org/10.1007/s00217-016-2707-z ER

Fischer, P. W. F., Vigneault, M., Huang, R., Arvaniti, K., & Roach, P. (2009). Sodium food sources in the Canadian diet. *Applied Physiology, Nutrition, and Metabolism*, *34*(5), 884–892. https://doi.org/10.1139/H09-077

Fouladkhah, A., Berlin, D., & Bruntz, D. (2015). High-sodium processed foods: Public health burden and sodium reduction strategies for industry practitioners. *Food Reviews International*, *31*(4), 341–354. https://doi.org/10.1080/87559129.2015.1022829

Freire, T. V. M., Freire, D. O., de Souza, V. R., Gonçalves, C. S., Carneiro, J. de D. S., Nunes, C. A. A., … Marques Pinheiro, A. C. (2015). Salting potency and Time-Intensity profile of microparticulated sodium chloride in shoestring potatoes. *Journal of Sensory Studies*, *30*(1), 1–9. https://doi.org/10.1111/joss.12129

Ganesan, B., Brown, K., Irish, D. A., Brothersen, C., & McMahon, D. J. (2014). Manufacture and sensory analysis of reduced- and low-sodium Cheddar and Mozzarella cheeses. *Journal of Dairy Science*, *97*(4), 1970–1982. https://doi.org/10.3168/jds.2013-7443

Gonçalves, C., Rodrigues, J. J. J., Júnior, H., Carneiro, J. J., Freire, T., Freire, L. L. L., … Freire, L. L. L. (2017). Sodium reduction in margarine using NaCl substitutes. *Anais Da Academia Brasileira De Ciencias*, *89*(3), 2505–2513. https://doi.org/10.1590/0001-3765201720150618

Graudal, N., & Jürgens, G. (2018). Conflicting evidence on health effects associated with salt reduction calls for a redesign of the salt dietary guidelines. *Progress in Cardiovascular Diseases*, *61*(1), 20–26. https://doi.org/10.1016/j.pcad.2018.04.008

Hayes, J. E., Sullivan, B. S., & Duffy, V. B. (2010). Explaining variability in sodium intake through oral sensory phenotype, salt sensation and liking. *Physiology and Behavior*, *100*(4), 369–380. https://doi.org/10.1016/j.physbeh.2010.03.017

Health Canada. (2018). Sodium intake of Canadians in 2017. Retrieved from https://www.canada.ca/en/health-canada/services/publications/food-nutrition/sodium-intake-canadians-2017.html

Henrique, N. A., Deliza, R., & Rosenthal, A. (2015). Consumer Sensory Characterization of Cooked Ham Using the Check-All-That-Apply (CATA) Methodology. *Food Engineering Reviews*, *7*(2), 265–273. https://doi.org/10.1007/s12393-014-9094-7

Hoppu, U., Hopia, A., Pohjanheimo, T., Rotola-Pukkila, M., Makinen, S., Pihlanto, A., & Sandell, M. (2017). Effect of salt reduction on consumer acceptance and sensory quality of food. *Foods*, *6*(12). https://doi.org/10.3390/foods6120103

Hubbard, E. M., Jervis, S. M., & Drake, M. A. (2016). The effect of extrinsic attributes on liking of cottage cheese. *Journal of Dairy Science*. https://doi.org/10.3168/jds.2015-9547

Inguglia, E. S., Zhang, Z., Tiwari, B. K., Kerry, J. P., & Burgess, C. M. (2017). Salt reduction strategies in processed meat products – A review. *Trends in Food Science & Technology*, *59*, 70–78. https://doi.org/10.1016/j.tifs.2016.10.016

Israr, T., Rakha, A., Sohail, M., Rashid, S., & Shehzad, A. (2016). Salt reduction in baked products: Strategies and constraints. *Trends in Food Science and Technology*, *51*, 98–105. https://doi.org/10.1016/j.tifs.2016.03.002

Jaeger, S. R. (2006). Non-sensory factors in sensory science research. *Food Quality and Preference*, *17*(1–2), 132–144. https://doi.org/10.1016/j.foodqual.2005.03.004

Jaenke, R., Barzi, F., McMahon, E., Webster, J., & Brimblecombe, J. (2017). Consumer acceptance of reformulated food products: A systematic review and meta-analysis of salt-reduced foods. *Critical Reviews in Food Science and Nutrition*, *57*(16), 3357–3372. https://doi.org/10.1080/10408398.2015.1118009

Jinap, S., Hajeb, P., Karim, R., Norliana, S., & Abdul-Kadir, S. Y. R. (2016). Reduction of sodium content in spicy soups using monosodium glutamate. *Food and Nutrition Research*, *60*, 1–11. https://doi.org/10.3402/fnr.v60.30463

Keast, R. S. J., & Breslin, P. A. S. (2003). An overview of binary taste-taste interactions. *Food Quality and Preference*, *14*(2), 111–124. https://doi.org/10.1016/S0950-3293(02)00110-6

Kloss, L., Meyer, J. D., Graeve, L., & Vetter, W. (2015). Sodium intake and its reduction by food reformulation in the European Union - A review. *NFS Journal*, *1*, 9–19. https://doi.org/10.1016/j.nfs.2015.03.001

Köster, E., & Mojet, J. (2018). Complexity of consumer perception. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 1* (Vol. 1, pp. 23–45). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102089-0.00002-9

Kremer, S., Mojet, J., & Shimojo, R. (2009). Salt reduction in foods using naturally brewed soy sauce. *Journal of Food Science*, *74*(6), S255–S262. https://doi.org/10.1111/j.1750-3841.2009.01232.x

Kremer, S., Shimojo, R., Holthuysen, N., Köster, E. P., & Mojet, J. (2013). Consumer acceptance of salt-reduced "soy sauce" foods over rapidly repeated exposure. *Food Quality and Preference*, *27*(2), 179–190. https://doi.org/10.1016/j.foodqual.2012.06.002

La Croix, K. W., Fiala, S. C., Colonna, A. E., Durham, C. A., Morrissey, M. T., Drum, D. K., & Kohn, M. A. (2015). Consumer detection and acceptability of reduced-sodium bread. *Public Health Nutrition*, *18*(8), 1412–1418. https://doi.org/10.1017/S1368980014001748

Lahne, J. (2018). Evaluation of meals and food pairing. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 2: Alternative approaches and special applications* (1st ed., Vol. 2, pp. 85–107). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-101743-2.00004-2

Lee III, W. E., & Pangborn, R. M. (1986). Time-intensity: The temporal aspects of sensory perception. *Food Technology, 40(11), 71-78. 82.* https://doi.org/10.1111/2041-210X.12508

Lee, S. H., Han, D. B., Caputo, V., & Nayga, R. M. (2015). Consumers' valuation for a reduced salt product: A nonhypothetical choice experiment. *Canadian Journal of Agricultural Economics*, *63*(4), 563–582. https://doi.org/10.1111/cjag.12081

Liem, D. G., Miremadi, F., & Keast, R. S. J. (2011). Reducing sodium in foods: The effect on flavor. *Nutrients*. https://doi.org/10.3390/nu3060694

Liem, D. G., Miremadi, F., Zandstra, E. H., & Keast, R. S. (2012). Health labelling can influence taste perception and use of table salt for reduced-sodium products. *Public Health Nutrition*, *15*(12), 2340–2347. https://doi.org/10.1017/s136898001200064x

Liem, D. G., Toraman Aydin, N., & Zandstra, E. H. (2012). Effects of health labels on expected and actual taste perception of soup. *Food Quality and Preference*, *25*(2), 192–197. https://doi.org/10.1016/j.foodqual.2012.02.015

Lopes, M., Cavaleiro, C., & Ramos, F. (2017). Sodium reduction in bread: A role for glasswort (Salicornia ramosissima J. Woods). *Comprehensive Reviews in Food Science and Food Safety*, *16*(5), 1056–1071. https://doi.org/10.1111/1541-4337.12277

Lorido, L., Estévez, M., & Ventanas, S. (2018). Fast and dynamic descriptive techniques (Flash Profile, Time-intensity and Temporal Dominance of Sensations) for sensory characterization of dry-cured loins. *Meat Science*, *145*, 154–162. https://doi.org/10.1016/j.meatsci.2018.06.028

Lorido, L., Hort, J., Estevez, M., & Ventanas, S. (2016). Reporting the sensory properties of dry-cured ham using a new language: Time intensity (TI) and temporal dominance of sensations (TDS). *Meat Science*, *121*, 166–174. https://doi.org/10.1016/j.meatsci.2016.06.009

Lucas, L., Riddell, L., Liem, D. G., Whitelock, S., & Keast, R. (2011). The influence of sodium on liking and consumption of salty food. *Journal of Food Science*, *76*(1). https://doi.org/10.1111/j.1750-3841.2010.01939.x

McCaughey, S. (2007). Dietary salt and flavor: mechanisms of taste perception and physiological controls. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods* (pp. 77–98). Woodhead Publishing Limited. https://doi.org/10.1533/9781845693046.1.77

McGough, M. M., Sato, T., Rankin, S. A., & Sindelar, J. J. (2012). Reducing sodium levels in frankfurters using naturally brewed soy sauce. *Meat Science*, *91*(1), 69–78. https://doi.org/10.1016/j.meatsci.2011.12.008

McLean, R., Hoek, J., & Hedderley, D. (2012). Effects of alternative label formats on choice of high- and low-sodium products in a New Zealand population sample. *Public Health Nutrition*, *15*(5), 783–791. https://doi.org/10.1017/s1368980011003508

McLean, R. M. (2014). Measuring population sodium intake: A review of methods. *Nutrients*, *6*(11), 4651–4662. https://doi.org/10.3390/nu6114651

Mente, A., O'Donnell, M., Rangarajan, S., McQueen, M., Dagenais, G., Wielgosz, A., … Yusuf, S. (2018). Urinary sodium excretion, blood pressure, cardiovascular disease, and mortality: a community-level prospective epidemiological cohort study. *The Lancet*, *392*(10146), 496–506. https://doi.org/10.1016/S0140-6736(18)31376-X

Noort, M. W. J., Bult, J. H. F., & Stieger, M. (2012). Saltiness enhancement by taste contrast in bread prepared with encapsulated salt. *Journal of Cereal Science*, *55*(2), 218–225. https://doi.org/10.1016/j.jcs.2011.11.012

Paulsen, M. T., Nys, A., Kvarberg, R., & Hersleth, M. (2014). Effects of NaCl substitution on the sensory properties of sausages: Temporal aspects. *Meat Science*, *98*(2), 164–170. https://doi.org/10.1016/j.meatsci.2014.05.020

Petersen, K. S., Rae, S., Venos, E., Malta, D., Trieu, K., Santos, J. A., … Arcand, J. A. (2019). Paucity of high-quality studies reporting on salt and health outcomes from the science of salt: A regularly updated systematic review of salt and health outcomes (April 2017 to March 2018). *Journal of Clinical Hypertension*, *21*(2), 307–323. https://doi.org/10.1111/jch.13450

Pineau, N., de Bouillé, A. G., Lepage, M., Lenfant, F., Schlich, P., Martin, N., & Rytz, A. (2012). Temporal Dominance of Sensations: What is a good attribute list? *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2012.04.004

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., … Köster, E. (2009). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455. https://doi.org/10.1016/j.foodqual.2009.04.005

Powles, J., Fahimi, S., Micha, R., Khatibzadeh, S., Shi, P., Ezzati, M., … Mozaffarian, D. (2013). Global, regional and national sodium intakes in 1990 and 2010: a systematic analysis of 24 h urinary sodium excretion and dietary surveys worldwide. *BMJ Open*, *3*(12), e003733. https://doi.org/10.1136/bmjopen-2013-003733

Rama, R., Chiu, N., Carvalho Da Silva, M., Hewson, L., Hort, J., & Fisk, I. D. (2013). Impact of salt crystal size on in-mouth delivery of sodium and saltiness perception from snack foods. *Journal of Texture Studies*, *44*(5), 338–345. https://doi.org/10.1111/jtxs.12017

Rodrigues, D. M., de Souza, V. R., Mendes, J. F., Nunes, C. A., & Pinheiro, A. C. M. (2016). Microparticulated salts mix: An alternative to reducing sodium in shoestring potatoes. *LWT - Food Science and Technology*, *69*, 390–399. https://doi.org/10.1016/j.lwt.2016.01.056

Rodrigues, J. F., Goncalves, C. S., Pereira, R. C., Carneiro, J. D. S., & Pinheiro, A. C. M. (2014). Utilization of temporal dominance of sensations and time intensity methodology for development of low-sodium Mozzarella cheese using a mixture of salts. *Journal of Dairy Science*, *97*(8), 4733–4744. https://doi.org/10.3168/jds.2014-7913

Rodrigues, J. F., Junqueira, G., Gonçalves, C. S., Carneiro, J. D. S., Pinheiro, A. C. M., & Nunes, C. A. (2014). Elaboration of garlic and salt spice with reduced sodium intake. *Anais Da Academia Brasileira de Ciencias*, *86*(4), 2065–2075. https://doi.org/10.1590/0001-3765201420130464

Schnettler, B., Ares, G., Sepúlveda, N., Bravo, S., Villalobos, B., Hueche, C., & Adasme-Berríos, C. (2019). How do consumers perceive reformulated foods after the implementation of nutritional warnings? Case study with frankfurters in Chile. *Food Quality and Preference*, *74*(December 2018), 179–188. https://doi.org/10.1016/j.foodqual.2019.01.021

Schnettler, B., Ares, G., Sepúlveda, N., Bravo, S., Villalobos, B., Hueche, C., & Lobos, G. (2019). Are consumers willing to pay more for reformulated processed meat products in the context of the implementation of nutritional warnings? Case study with frankfurters in Chile. *Meat Science*, *152*(February), 104–108. https://doi.org/10.1016/j.meatsci.2019.02.007

Shan, L. C., De Brún, A., Henchion, M., Li, C., Murrin, C., Wall, P. G., & Monahan, F. J. (2017). Consumer evaluations of processed meat products reformulated to be healthier – A conjoint analysis study. *Meat Science*, *131*, 82–89. https://doi.org/10.1016/j.meatsci.2017.04.239

Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2016). Current status of salt reduction in bread and bakery products – A review. *Journal of Cereal Science*, *72*, 135–145. https://doi.org/10.1016/j.jcs.2016.10.010

Silow, C., Zannini, E., Axel, C., Lynch, K. M., & Arendt, E. K. (2016). Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, *89*, 330–337. https://doi.org/10.1016/j.foodres.2016.08.031

Silva, H. L. A., Balthazar, C. F., Silva, R., Vieira, A. H., Costa, R. G. B., Esmerino, E. A., … Cruz, A. G. (2018). Sodium reduction and flavor enhancer addition in probiotic prato cheese: Contributions of quantitative descriptive analysis and temporal dominance of sensations for sensory profiling. *Journal of Dairy Science*, *101*(10), 8837–8846. https://doi.org/10.3168/jds.2018-14819

Sinopoli, D. A., & Lawless, H. T. (2012). Taste properties of potassium chloride alone and in mixtures with sodium chloride using a Check-All-That-Apply method. *Journal of Food Science*, *77*(9). https://doi.org/10.1111/j.1750-3841.2012.02862.x

Sodium Working Group Canada. (2010). *Sodium reduction strategy for Canada*. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating/sodium/related-information/reduction-strategy/recommendations-sodium-working-group.html

Soto-Escageda, J. A., Estañol-Vidal, B., Vidal-Victoria, C. A., Michel-Chávez, A., Sierra-Beltran, M. A., & Bourges-Rodríguez, H. (2016). Does salt addiction exist? *Salud Mental*, *39*(3), 175–181. https://doi.org/10.17711/SM.0185-3325.2016.016

Stieger, M. A., Bult, J. H. F., Hamer, R. J., & Noort, M. W. J. (2009). Food product with inhomogeneous tastant bulk distribution and method for making such food product. *The effects of brief mindfulness intervention on acute pain experience: An examination of individual difference*. https://doi.org/10.1017/CBO9781107415324.004

Stieger, M., & Van de Velde, F. (2013). Microstructure, texture and oral processing: New ways to reduce sugar and salt in foods. *Current Opinion in Colloid and Interface Science*, *18*(4), 334–348. https://doi.org/10.1016/j.cocis.2013.04.007

Sukkwai, S., Kijroongrojana, K., Chonpracha, P., Pujols, K. D., Alonso-Marenco, J. R., Ardoin, R., & Prinyawiwatkul, W. (2018). Effects of colorant concentration and 'natural colour' or 'sodium content' claim on saltiness perception, consumer liking and emotion, and purchase intent of dipping sauces. *International Journal of Food Science and Technology*, *53*(5), 1246–1254. https://doi.org/10.1111/ijfs.13704

Tórtora, G., Machín, L., & Ares, G. (2019). Influence of nutritional warnings and other label features on consumers' choice: Results from an eye-tracking study. *Food Research International*, *119*(September 2018), 605–611. https://doi.org/10.1016/j.foodres.2018.10.038

Trieu, K., McLean, R., Johnson, C., Santos, J. A., Angell, B., Arcand, J. A., … Webster, J. (2016). The science of salt: A regularly updated systematic review of the implementation of salt reduction interventions (June–October 2015). *Journal of Clinical Hypertension*, *18*(6), 487–494. https://doi.org/10.1111/jch.12806

Trieu, K., McMahon, E., Santos, J. A., Bauman, A., Jolly, K.-A., Bolam, B., & Webster, J. (2017). Review of behaviour change interventions to reduce population salt intake. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 17. https://doi.org/10.1186/s12966-017-0467-1

Trieu, K., Neal, B., Hawkes, C., Dunford, E., Campbell, N., Rodriguez-Fernandez, R., … Webster, J. (2015). Salt reduction initiatives around the world – A systematic review of progress towards the global target. *PLoS ONE*, *10*(7), 1–22. https://doi.org/10.1371/journal.pone.0130247

Vázquez, M. B., Curia, A., & Hough, G. (2009). Sensory descriptive analysis, sensory acceptability and expectation studies on biscuits with reduced added salt and increased fiber. *Journal of Sensory Studies*, *24*(4), 498–511. https://doi.org/10.1111/j.1745-459X.2009.00223.x

Ventanas, S., Puolanne, E., & Tuorila, H. (2010). Temporal changes of flavour and texture in cooked bologna type sausages as affected by fat and salt content. *Meat Science*, *85*(3), 410–419. https://doi.org/10.1016/j.meatsci.2010.02.009

Webster, J., Trieu, K., Dunford, E., & Hawkes, C. (2014). Target salt 2025: A global overview of national programs to encourage the food industry to reduce salt in foods. *Nutrients*, *6*(8), 3274–3287. https://doi.org/10.3390/nu6083274

Wendin, K., Langton, M., Caous, L., & Hall, G. (2000). Dynamic analyses of sensory and microstructural properties of cream cheese. In *Food Chemistry* (Vol. 71, pp. 363–378). https://doi.org/10.1016/S0308-8146(00)00200-4

Willems, A. A., Van Hout, D. H. A., Zijlstra, N., & Zandstra, E. H. (2013). Effects of salt labelling and repeated in-home consumption on long-term liking of reduced-salt soups. *Public Health Nutrition*, *17*(5), 1130–1137. https://doi.org/10.1017/S1368980013001055

World Health Organization. (2006). *Reducing salt intake in populations*. *WHO*. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/43653/9789241595377_eng.pdf

World Health Organization. (2014). Guideline: sodium intake for adults and children. *Guideline: Sodium Intake for Adults and Children*, 1–46. Retrieved from http://www.who.int/nutrition/publications/guidelines/sodium_intake/en/

World Health Organization. (2016). *The SHAKE technical package for salt reduction*. Retrieved from http://www.who.int/dietphysicalactivity/publications/shake-salt-habit/en/

Xin Wei Goh, F., Itohiya, Y., Shimojo, R., Sato, T., Hasegawa, K., & Lai Peng, L. (2011). Using naturally brewed soy sauce to reduce salt in selected foods. *Journal of Sensory Studies*, *26*(6), 429–435.

Zandstra, E. H., De Graaf, C., Mela, D. J., & Van Staveren, W. A. (2000). Short- and long-term effects of changes in pleasantness on food intake. *Appetite*. https://doi.org/10.1006/appe.1999.0304

Zandstra, E. H., Lion, R. R., & Newson, R. S. (2016). Salt reduction: Moving from consumer awareness to action. *Food Quality and Preference*, *48*, 376–381. https://doi.org/10.1016/j.foodqual.2015.03.005

Zandstra, E. H., Willems, A. A., & Lion, R. (2018). Making salt-reduced products more appealing to consumers: impact of front-of-pack messages on liking and table salt use over time. *Public Health Nutrition*, *21*(15), 2762–2772. https://doi.org/10.1017/S1368980018001714

Chapter 2. A comparison of sensory attribute profiles and liking between regular and sodium-reduced food products

2.1. Introduction

Globally, dietary salt intake is consistently higher than recommended by the World Health Organization (Health Canada, 2018b; Powles et al., 2013). Recent studies confirm that excessive consumption of sodium results in negative health consequences such as hypertension, cardiovascular disease and stroke (Cappuccio et al., 2019; Graudal, Hubeck-Graudal, & Jürgens, 2016; Mente et al., 2018; World Health Organization, 2016) and the subsequent need to reduce sodium in the diet. As in many industrialized countries, the majority of sodium in the typical Canadian diet comes from processed foods, such as bakery products, processed meats, vegetable-based dishes, soups, dairy products, gravies and sauces, potato chips and salty snacks (Health Canada, 2018b). Successful sodium intake reduction requires both sodium reduction in processed foods and a change in consumer behaviors (Arcand et al., 2016; Sodium Working Group Canada, 2010).

A range of strategies to develop sodium-reduced foods has been applied, including gradual sodium reduction of food formulations, the use of salt substitutes or flavor enhancers, and changes in the physical form of salt and improvement of salt diffusion by novel technologies such as high pressure or ultrasound (Inguglia et al., 2017; Silow, Axel, et al., 2016). Despite these efforts, sodium reduction in processed foods is often unsuccessful as salt reduction leads to changes in sensory perceptions of the product, important contributors to consumer preference and satisfaction with foods (Inguglia et al., 2017; Israr et al., 2016; Liem et al., 2011). Salty taste perception is influenced by food texture and interactions with other taste compounds (Liem et al., 2011). In breads and bakery products, where salty is not a dominant flavor, sodium is responsible for overall flavor impression, enhancing sweetness as well as masking bitterness (Silow, Axel, et al., 2016). Sodium reduction therefore affects not only salty taste of a food, but also other flavors, texture and appearance (Inguglia et al., 2017; Israr et al., 2016). Sodium reduction levels are achieved differently across product types, i.e. up to 37% in breads and 67% in processed meats, without changing consumer acceptability (Jaenke et al., 2017).

Consumer behavior and food choice are influenced by many interacting factors (Köster & Mojet, 2018). Most studies of food reformulation for salt reduction have focused on product sensory attributes and hedonic perception (Inguglia et al., 2017; Israr et al., 2016; Jaenke et al., 2017). Various consumer attributes, such as taste sensitivity, demographics, body mass index (BMI), health status, sodium intake, and usual intake of dietary salt sources have been evaluated for their potential association with salt taste sensitivity and liking (Hayes et al., 2010; McLean, 2014; Zandstra et al., 2016). Oral sensory phenotype, i.e. PROP taster status and taste papillae number, is associated with salt sensation and liking, and sodium intake (Hayes et al., 2010).

Preference for regular and sodium-reduced processed foods is dependent on food experience and dietary habits. In addition to universal salt liking, consumers are often unaware of their own salt intake level and dietary sources of salt (McLean, 2014). Little is known about the associations between intake of usual dietary sodium sources and sensory perception of regular and sodium-reduced foods. This knowledge is important to generate appealing sodium-reduced foods, especially for individuals with high dietary sodium intake.

The objectives of this study were (1) to compare sensory profiles and overall liking between regular and sodium-reduced formulations of processed food products that make substantial sodium contributions to the Canadian diet; (2) to examine the influence of individual sensory acuity and consumption frequency of dietary sodium sources on sensory perception and liking of common regular and sodium-reduced food products available in the marketplace. Commercial food products used in this study, potato chips, pickles, cooked ham and chicken noodle soup, represent formulations currently available in the market. Similar to most industrialised countries, a few staple food items are the main sodium sources in the Canadian diet, i.e. bread, cereals and bakery products, meat and meat products, cheese and dairy products (Health Canada, 2018b; Kloss et al., 2015). In the Canadian market, no sodium-reduced formulations for bread, cereals and bakery products, dry cured meat products, cheese and dairy products were available for evaluation.

2.2. Material and methods

2.2.1. Participants

One hundred volunteer participants (70% female, 68% aged 18-29 years old) (Table 2.1) were recruited from staff and students at the University of Alberta (Edmonton, AB, Canada). Participants were eligible for the study if they were age 18+ years, healthy and regular consumers of the study products. Exclusion criteria included smoking, pregnancy or having a thyroid condition. The study protocol was approved by a Research Ethics Board at the University of Alberta. Participants completed written informed consent and received a gift card in acknowledgement of their time and contribution to the study.

Table 2.1. Demographics and sensory acuity for all participants and three participant clusters of Dietary Sodium Sources (DSS).

		All participants (n=100)	**Low DSS (n=27)**	**Moderate DSS (n=33)**	**High DSS (n=40)**
Sex, %	Female	70	67	73	70
	Male	30	33	27	30
Age, %	18-29 years	68	56	85	62
	30-39 years	17	26	12	15
	40+ years	15	19	3	22
Taster status, %	Supertaster	71	74	82	60
	Taster	18	15	12	25
	Non-taster	11	11	6	15
Sodium chloride detection threshold, mM (Geometric mean)		6.02	4.64	6.31	7.22

2.2.2. Food samples and preparation

Four pairs of commonly consumed food products were selected to represent a range of regular and sodium-reduced items available in the marketplace; potato chips, dill pickles, cooked ham and chicken noodle soup (Table 2.2). Two potato chips for each sample (approximately 1 g per chip) were served in 162 mL clear plastic cups with lids. Dill pickle ends were removed and each pickle was cut into quarters about 3 cm in length. Two pieces of dill pickles were served in 103 mL clear plastic cups with lids. Hams were sliced into 1x2x3 (cm) pieces; two pieces of each ham sample were served in 103 mL clear plastic cups with lids. Soup samples were prepared following the manufacturer's instruction and kept at 60 ºC in double boilers before serving 50 mL samples in 103 mL styrofoam cups with lids. Chips, pickles and ham were served at room temperature. All samples were blinded with random 3-digit codes, and sample orders were balanced among participants. Distilled water and unsalted crackers were provided to cleanse the palate between samples.

2.2.3. Procedure

Participants were asked to complete three tasting tasks; sensory evaluation of four pairs of food products, a salt detection threshold test and a taster status test, as well as online questionnaires of demographics and consumption frequencies of common dietary sodium sources. In order to avoid sensory fatigue, this study took place over two tasting sessions on different days. Each tasting session took no longer than 30 min. In session one, participants completed the salt threshold test and evaluation of two pairs of food products. Prior to the second session participants completed the online questionnaires. In session two, participants evaluated the other two pairs of food products and completed the taster status test.

Table 2.2. Study food products' brands, ingredients and declared sodium and potassium content.

Product	Brand	Ingredients	Sodium content	Potassium content
Regular chips	Lay's Classic Chips, PEPSICO, Canada	Potatoes, vegetable oil, salt	330 mg/ 50 g	-
Sodium-reduced chips	Lay's Lightly Salted Chips with 50% less sodium, PEPSICO, Canada	Potatoes, vegetable oil, salt	160 mg/ 50 g	-
Regular pickles	Bick's Garlic Dill Pickles, Smucker Foods of Canada Corp., ON, Canada	Cucumbers, water, white vinegar, salt, dehydrated garlic, calcium chloride, polysorbate 80, seasonings	270 mg/ 30 g	0
Sodium-reduced pickles	Bick's 50% Less Salt Garlic Whole Dill Pickles, Smucker Foods of Canada Corp., ON, Canada	Cucumbers, water, white vinegar, potassium chloride, salt, dehydrated garlic, calcium chloride, polysorbate 80, seasonings	135 mg/ 30 g	190 mg/30 g
Regular ham	Schneiders Olde Fashioned Ham, Maple Leaf Foods Inc., MB, Canada	Ham, water, salt, corn syrup solids, potassium lactate, sodium phosphate, sodium diacetate, sodium erythorbate, sodium nitrite, smoke	490 mg/ 55 g	0
Sodium-reduced ham	Schneiders Olde Fashioned Ham - 25% Less Sodium, Maple Leaf Foods Inc., MB, Canada	Pork, water, corn syrup solids, potassium lactate, salt, potassium chloride, potassium phosphate, carrageenan, sodium diacetate, sodium erythorbate, sodium nitrite, smoke	370 mg/ 55 g	750 mg/ 55 g
Regular soup	Lipton Chicken Noodle, Unilever Canada, ON, Canada	Wheat noodles, salt, corn syrup solids, chicken fat, hydrolyzed soy protein, chicken fat, corn starch, modified palm oil, monosodium glutamate, onion powder, dehydrated mechanically separated cooked chicken, spice, natural flavour, dried parsley, disodium inosinate, disodium guanylate, and yeast extract.	780 mg / 21 g soup powder/ 250 mL soup	-
Sodium-reduced soup	Lipton Chicken Noodle - 25% Less Sodium, Unilever Canada, ON, Canada	Wheat noodles, salt, hydrolyzed soy & corn protein, maltodextrin, corn starch, chicken fat, onion powder, dehydrated mechanically separated cooked chicken, natural flavour, potassium chloride, yeast extract, spice, disodium guanylate, disodium inosinate, dried parsley	480 mg/ 19 g soup powder/ 250 mL soup	-

2.2.3.1. Sensory profiles and liking of food samples

Participants were asked to rate their overall liking of each sample using 9-point hedonic scales ('Dislike extremely' to 'Like extremely'), perceived saltiness by using a 5-point Just-About-Right (JAR) scale ('Not salty enough' to 'Much too salty') and other sensory attributes by using Rate-All-That-Apply (RATA) with 3-point scale (low, medium and high). RATA is a variation of the CATA (Check-All-That-Apply) question format; a widely used quick and easy method to obtain consumer-based sensory product characterization. RATA allows each consumer to rate the intensity of the applicable product attributes using a category scale (Ares et al., 2014). Sensory attributes for each food product were generated by a previous panel, in which 12 participants tasted samples and generated terms to describe differences between a regular product and its sodium-reduced counterpart. A maximum of ten most highly cited attributes for each product were used for the RATA questionnaires.

2.2.3.2. Salty taste detection threshold

Salty taste detection threshold was assessed by the Ascending Method of Limits (AML). Eight sodium chloride solutions (0.25 - 32 mM, adapted from the ISO 3972 (ISO, 2011)) with successive 50% dilutions were prepared from a 256 mM sodium chloride (Fisher Scientific, MA, USA) solution. Each sodium chloride solution was paired with a sample of distilled water, with randomized order of presentation within pairs. Eight sample sets were served to each participant at room temperature in order of increasing sodium chloride concentration. For each sample, participants were asked to determine whether they detected the presence of taste (something other than water) after swishing the whole sample in their mouth for 10 sec and then expectorating. Each tasting was preceded with a water rinse. Individual detection threshold was defined as the lowest concentration of three consecutive correctly identified solutions.

2.2.3.3. Taster status

The taster status test is a simple standard test to determine taster status based on perceived intensity of a PROP (6-n-propylthiouracil) solution (Bartoshuk, Duffy, & Miller, 1994; Hayes & Keast, 2011). Participants were asked to place a 10 mL sample of 3.2 mM PROP solution in the mouth for 10 sec, expectorate the solution, then rate the bitterness on the labeled magnitude scale (LMS) from 'barely detectable' to 'strongest imaginable'. Participants were classified as supertaster if they scored in the range from very strong to strongest imaginable, taster if they scored in the range from moderate to very strong, and non-taster if they scored in the range from barely detectable to weak (Zhao, Kirkmeyer, & Tepper, 2003).

2.2.3.4. Dietary Sodium Sources - Food Frequency Questionnaire (DSS - FFQ)

Participants completed an online questionnaire to describe their consumption frequency of 13 groups of dietary sodium sources. The food groups were sourced from published studies that identified significant sodium food sources in the Canadian diet (Arcand et al., 2016; Fischer et al., 2009), including breads, processed meats, cheese, canned vegetables and legumes (including pickles), salted butter and margarine, cooking sauces, table sauces, soup, mixed dishes, fish and seafood, potato chips and salty snacks, breakfast cereals and sports drinks. Frequency of consumption response options ("Almost never", "1-2 times per month", "1 time per week", "2-3 times per week" and "Almost every day") were typical of qualitative food frequency questionnaires (Pérez Rodrigo, Aranceta, Salvador, & Varela-Moreiras, 2015). We developed our own DSS-FFQ as FFQ are tailored to specific study groups and research purposes to ensure cultural appropriateness (Pérez Rodrigo et al., 2015; Ponce-Martínez et al., 2018; Rios-Leyvraz et al., 2018). Additionally, participants indicated their sex, age range, diet type (Canadian, European, Chinese or other), and the habit of adding salt to foods at mealtime (before or after tasting the food, or almost never).

2.2.4. Data analysis

RATA data were treated as continuous; the points of the scale were scored from 0-3 (0=None, 1=Low, 2=Medium, 3=High) (Ares et al., 2014; Meyners, Jaeger, & Ares, 2016). Hierarchical Clustering on Principal Components (HCPC) analysis of the DSS-FFQ data was used to clusterise participants into groups by consumption frequency of DSS (low, moderate, high). The mean and standard deviation (sd) of ratings for overall liking and attribute intensities assessed by RATA, and the geometric mean of threshold data, were calculated for all participants and each DSS cluster. For all participants and DSS clusters, the significant differences in overall liking and perceived attribute intensities between the regular and sodium-reduced products were determined by paired Wilcoxon signed rank test (*p-value* < 0.05). Penalty analysis was performed on JAR saltiness and overall liking data for each product for all participants and each DSS cluster. Penalty analysis plots were used to show penalties, mean drops in overall liking, for each non-JAR saltiness category for each of the regular and sodium-reduced products. The significant non-JAR categories having significant penalties (significantly different from 0 with *p-value* < 0.05, ANOVA followed by multiple range tests), are highlighted with a "*" in penalty analysis plots. Categories in the upper right-hand corner of penalty analysis plots had the highest skews and were associated with the greatest penalties. Only significant non-JAR categories with a substantial proportion of participants (> 20%) were considered for interpretation of results. Comparisons between taster groups based on DSS, sensory attribute perception and liking were not conducted as most participants were supertasters (Table 2.1). All data analyses were carried out using R version 3.4.1 (R Core Team, 2017) and *FactoMineR* package (Lê, Josse, & Husson, 2008) at a significance value of $p < 0.05$.

2.3. Results

2.3.1. Differences in sensory profiles and liking between regular and sodium-reduced products

Sensory profiles and overall liking of regular and sodium-reduced food products of all participants are presented in Table 2.3. Not surprisingly, sodium reduced products exhibited significantly lowered perceived saltiness in all evaluated foods. The saltiness was perceived as about medium intensity for regular chips and soup, regular and sodium-reduced pickles and ham, while the saltiness of sodium-reduced chips and soup were at low intensity with means of 1.2 on the 3-point scale. Moreover, consumers perceived sodium-reduced foods with decreased intensity of some other sensory attributes for potato chips (*oily* and *flavorful*) and ham (*seasoning* and *juicy)*, decreased intensity of all evaluated sensory attributes for chicken noodle soup, and increased *garlic* intensity of pickles.

Although the regular and sodium-reduced products were different in sensory attributes, their overall liking was different for dill pickles and chicken noodle soup, but not for potato chips and ham. The sodium-reduced pickles were liked more. Conversely, the regular soup was liked more. However, the differences in mean liking ratings for the regular and sodium reduced pickles and soup were within 1 point on the 9-point scale (respectively 5.3 and 5.8 for pickles, 6.6 and 6.1 for soup); the regular pickles were *neither liked nor disliked* while the sodium-reduced pickles were *liked slightly*; the regular soup was *liked slightly* while the sodium-reduced soup was *liked moderately*. Both regular and sodium-reduced chips were *liked moderately*; both regular and sodium-reduced hams were *liked slightly*.

Table 2.3. Sensory profiles[a] and overall liking[b] of regular and sodium-reduced food products (mean(sd)) by all participants and 3 participant clusters of Dietary Sodium Sources (DSS).

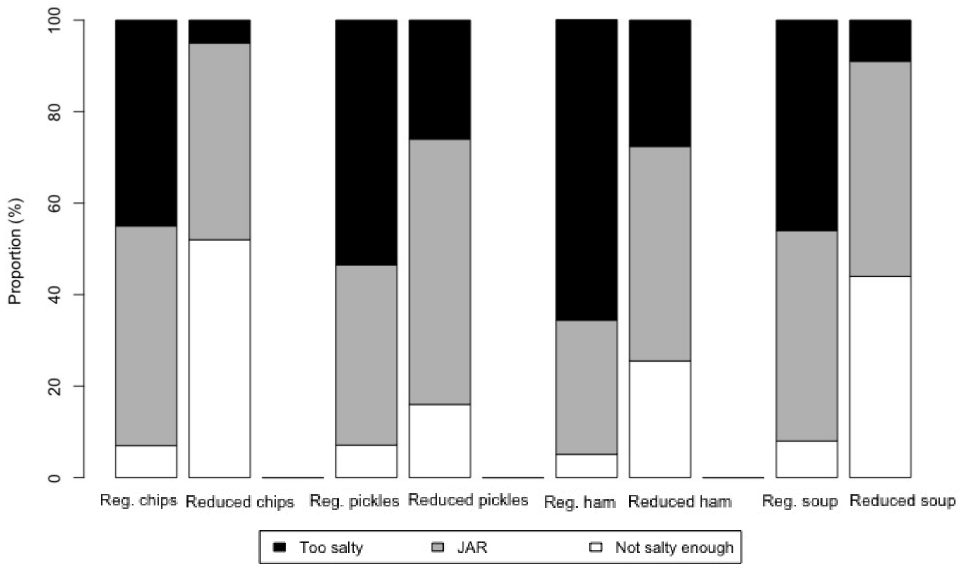
Food product	Sensory attributes	All participants (n=100)			Low DSS (n=27)			Moderate DSS (n=33)			High DSS (n=40)		
		Regular	Sodium-reduced	Significance	Regular	Sodium-reduced	Significance	Regular	Sodium-reduced	Significance	Regular	Sodium-reduced	Significance
Chips	Overall liking	6.8 (1.4)	6.8 (1.4)		6.9 (1.4)	7.0 (1.4)		6.3 (1.6)	6.8 (1.4)		7.0 (1.3)	6.6 (1.4)	
	Oily	1.8 (0.7)	1.5 (0.7)	**	2.0 (0.8)	1.7 (0.6)		1.8 (0.6)	1.5 (0.7)	*	1.6 (0.8)	1.4 (0.7)	
	Salty	2.2 (0.7)	1.2 (0.6)	***	2.0 (0.7)	1.3 (0.6)	***	2.4 (0.7)	1.3 (0.6)	***	2.0 (0.6)	1.1 (0.6)	***
	Potato	2.0 (0.7)	2.1 (0.7)		2.1 (0.6)	2.3 (0.7)		2.1 (0.8)	2.3 (0.6)		2.0 (0.8)	2.0 (0.7)	
	Vegetable	1.1 (0.8)	1.2 (0.9)		1.0 (0.8)	1.0 (0.8)		1.1 (0.8)	1.3 (1.1)		1.3 (0.9)	1.2 (0.9)	
	Flavorful	1.9 (0.8)	1.5 (0.8)	***	1.6 (0.8)	1.3 (0.8)		1.9 (0.7)	1.8 (0.8)		2.0 (0.8)	1.4 (0.7)	***
	Crunchy	2.6 (0.6)	2.5 (0.6)		2.5 (0.6)	2.6 (0.5)		2.6 (0.5)	2.4 (0.7)		2.6 (0.6)	2.5 (0.6)	
	Dry	1.9 (0.8)	1.9 (0.9)		1.6 (0.8)	1.7 (0.9)		2.2 (0.8)	2.2 (0.8)		1.8 (0.8)	1.8 (0.9)	
Pickles	Overall liking	5.3 (1.9)	5.8 (2.0)	*	5.6 (1.9)	6.1 (1.9)		4.4 (1.9)	4.9 (2.2)		6.0 (1.6)	6.4 (1.6)	
	Sour	2.2 (0.8)	2.1 (0.8)		2.2 (0.9)	1.7 (0.8)	**	2.5 (0.6)	2.5 (0.6)		1.9 (0.7)	1.9 (0.9)	
	Salty	2.1 (0.7)	1.8 (0.7)	***	2.2 (0.7)	1.7 (0.9)	*	2.3 (0.7)	2.0 (0.7)	*	2.0 (0.7)	1.6 (0.7)	*
	Bitter	0.8 (0.9)	0.8 (0.9)		0.9 (0.9)	0.7 (0.7)		0.5 (0.8)	0.6 (0.8)		1.1 (0.9)	1.0 (1.0)	
	Vinegar	2.3 (0.8)	2.3 (0.8)		2.4 (0.7)	2.1 (0.8)		2.3 (0.9)	2.5 (0.7)		2.2 (0.8)	2.2 (0.8)	
	Dill	1.7 (0.9)	1.7 (0.9)		1.5 (1.0)	1.3 (1.1)		1.7 (0.9)	1.8 (0.9)		1.8 (0.8)	1.8 (0.6)	
	Garlic	1.0 (0.9)	1.2 (0.9)	*	0.8 (0.8)	0.9 (1.0)		0.8 (1.0)	1.1 (0.9)		1.2 (0.8)	1.4 (0.9)	*
	Tangy	1.8 (0.9)	1.7 (0.9)		1.6 (0.9)	1.2 (0.8)		1.8 (0.9)	1.9 (0.8)		1.9 (0.9)	1.9 (0.9)	
	Tough	1.1 (0.8)	1.0 (0.8)		1.2 (0.8)	1.1 (0.8)		1.1 (0.9)	1.2 (0.8)		1.0 (0.8)	0.8 (0.7)	
	Crunchy	2.0 (0.7)	2.1 (0.8)		2.0 (0.7)	2.1 (0.7)		1.9 (0.7)	2.1 (0.8)	*	2.2 (0.8)	2.2 (0.7)	
	Aftertaste	1.8 (0.9)	1.7 (0.9)		1.9 (0.9)	1.7 (1.0)		1.8 (1.0)	1.8 (0.9)		1.8 (0.9)	1.8 (0.8)	
Ham	Overall liking	6.1 (1.4)	6.0 (1.7)		6.4 (1.1)	6.3 (1.4)		5.7 (1.4)	5.8 (1.6)		6.1 (1.4)	6.1 (1.9)	
	Salty	2.4 (0.7)	1.7 (0.8)	***	2.5 (0.7)	1.5 (0.6)	***	2.7 (0.5)	2.1 (0.8)	**	2.1 (0.8)	1.6 (0.8)	**
	Bitter	0.5 (0.6)	0.5 (0.6)		0.4 (0.7)	0.5 (0.6)		0.4 (0.6)	0.5 (0.7)		0.6 (0.7)	0.6 (0.6)	
	Ham	2.3 (0.7)	2.3 (0.8)		2.3 (0.7)	2.1 (0.8)		2.2 (0.7)	2.5 (0.8)		2.2 (0.7)	2.2 (0.8)	
	Smoke	1.4 (0.8)	1.4 (0.8)		1.4 (0.9)	1.1 (0.8)		1.5 (0.9)	1.5 (1.0)		1.3 (0.7)	1.4 (0.7)	
	Seasoning	1.6 (0.8)	1.2 (0.8)	***	1.5 (0.7)	1.0 (0.7)	**	1.7 (0.9)	1.4 (0.9)	*	1.5 (0.7)	1.2 (0.6)	**
	Fatty	1.5 (0.8)	1.4 (0.8)		1.5 (0.9)	1.2 (0.8)		1.4 (0.7)	1.4 (0.6)		1.6 (0.8)	1.5 (0.9)	
	Juicy	1.8 (0.8)	1.7 (0.8)	*	1.8 (0.9)	1.4 (0.8)	*	1.7 (0.8)	1.5 (0.6)		2.0 (0.7)	2.0 (0.8)	
	Tough	1.1 (0.8)	1.2 (0.8)		1.0 (0.8)	1.4 (0.9)	*	1.3 (0.7)	1.3 (0.7)		1.0 (0.8)	1.1 (0.9)	
	Stringy	1.1 (0.9)	1.2 (0.9)		1.3 (0.8)	1.3 (1.0)		1.3 (0.9)	1.4 (0.8)		1.0 (0.9)	0.9 (0.8)	
Soup	Overall liking	6.6 (1.4)	6.1 (1.6)	*	6.6 (1.2)	6.4 (1.3)		6.4 (1.4)	6.0 (1.6)		6.7 (1.5)	6.0 (1.7)	*
	Salty	2.0 (0.6)	1.2 (0.6)	***	2.0 (0.7)	1.3 (0.6)	***	2.2 (0.6)	1.5 (0.6)	***	2.0 (0.7)	1.0 (0.6)	***
	Umami	1.7 (0.9)	1.4 (0.8)	**	1.8 (0.9)	1.5 (0.9)		2.0 (0.7)	1.8 (0.7)		1.3 (1.0)	1.1 (0.8)	*
	Chicken broth	2.0 (0.7)	1.6 (0.8)	***	2.1 (0.7)	1.4 (0.8)	***	2.1 (0.7)	1.6 (0.7)	*	1.9 (0.8)	1.6 (0.8)	*
	Seasoning	2.0 (0.8)	1.5 (0.7)	***	2.0 (0.7)	1.4 (0.7)	***	2.1 (0.8)	1.7 (0.8)	**	1.8 (0.7)	1.4 (0.6)	**
	Flavorful	2.0 (0.8)	1.5 (0.7)	***	2.0 (0.8)	1.3 (0.6)	***	2.2 (0.7)	1.7 (0.8)	***	1.9 (0.8)	1.4 (0.8)	**
	Oily	1.6 (0.9)	1.2 (0.8)	***	1.8 (0.9)	1.2 (0.9)	**	1.5 (0.8)	1.2 (0.8)	*	1.6 (0.9)	1.1 (0.7)	**

[a]: *3-point scale of 1 (Low) to 3 (High)*
[b]: *9-point scale of 1 (Dislike extremely) to 9 (Like extremely)*
*: *p-value ≤ 0.05, **: p-value ≤ 0.01, ***: p-value ≤ 0.001*

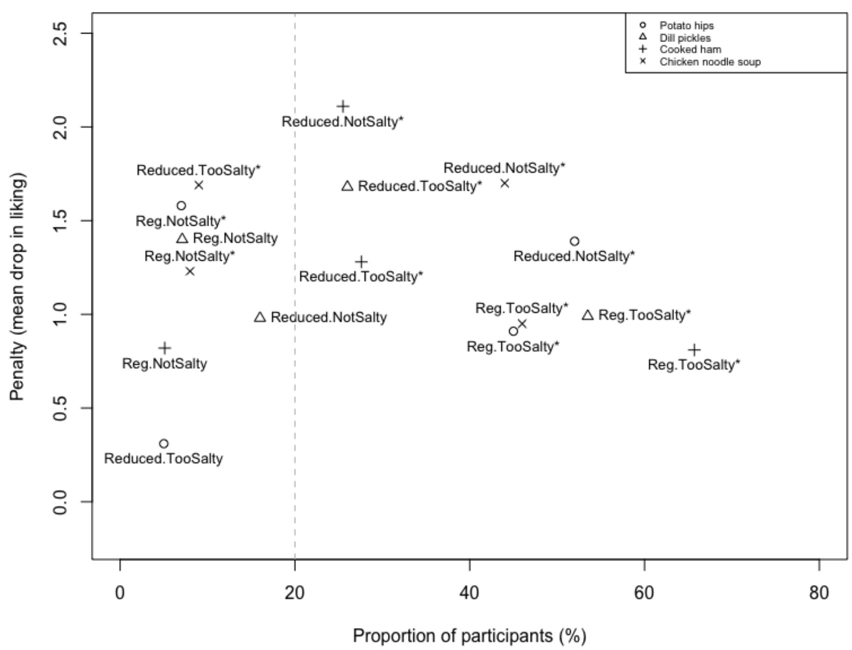
The majority of participants perceived regular products as JAR or *too salty* (Figure 2.1a). All regular products were perceived as *too salty* by at least 45% of participants. Compared to the regular products, the proportion of participants who perceived the sodium-reduced product as *too salty* was less while the proportion of participants who perceived the sodium-reduced product as *not salty enough* was greater. Penalty analysis (Figure 2.1b) revealed that perceived JAR saltiness significantly influenced liking of all evaluated products.

Groups within the population responded differently to sodium reduction of food products; lower saltiness decreased product liking for some participants but increased it for others. The majority of participants (65.7%) perceived the regular ham as *too salty* and associated with a significant overall liking penalty while the sodium-reduced ham had a smaller proportion for the *too salty* category and a larger proportion for the *JAR* category, which suggested that there was a sub group whose liking increased with the decrease in perceived saltiness. Of the participants, 27.6% perceived sodium-reduced ham as *too salty* and associated with a significant liking penalty, which suggested that further saltiness reduction may increase their liking. In contrast, 25.5% of participants rated the sodium-reduced ham as *not salty enough,* which suggested that the lower saltiness decreased overall liking for some participants. Similarly, for chips and soup, while both the regular and sodium-reduced products were perceived as JAR salty by comparable proportions of participants, nearly half the participants perceived the regular product as *too salty* (45% for chips and 46% for soup) and the sodium-reduced product as *not salty enough* (52% for chips and 44% for soup), with significant liking penalties.

Saltiness was a key driver of pickle liking; low JAR saltiness (*not salty enough*) was associated with greater liking for pickles. The proportion of participants who perceived regular pickles as *too salty* decreased from 53.5% for regular pickles to 26% for sodium-reduced pickles. The *too salty* category associated with a significant liking penalty for both regular and sodium-reduced pickles. Additionally, the majority of participants (58%) perceived sodium-reduced pickles as *JAR* salty.



(a)



**: significant non-JAR saltiness categories*

(b)

Figure 2.1. JAR saltiness (a) and penalty analysis for JAR saltiness and liking (b) of the regular (Reg.) and sodium-reduced (Reduced) food products evaluated by all participants (n=100).

2.3.2. Associations of consumption frequency of dietary sodium sources (DSS) with sensory profiles and product liking

2.3.2.1. Consumption frequencies of DSS

Hierarchal cluster analysis of DSS-FFQ data revealed three clusters representative of different consumption frequencies of DSS; low, moderate and high DSS. The DSS clusters associated with participant age groups, diets (Canadian, Chinese, European and other) and consumption frequencies of sodium sources (Figure 2.2). There were no significant associations between DSS clusters and sex, individual salt detection threshold or taster status. The mean sodium chloride threshold value for all participants was 6.02 mM, and increased with increasing frequency consumption level of DSS (Table 2.1).

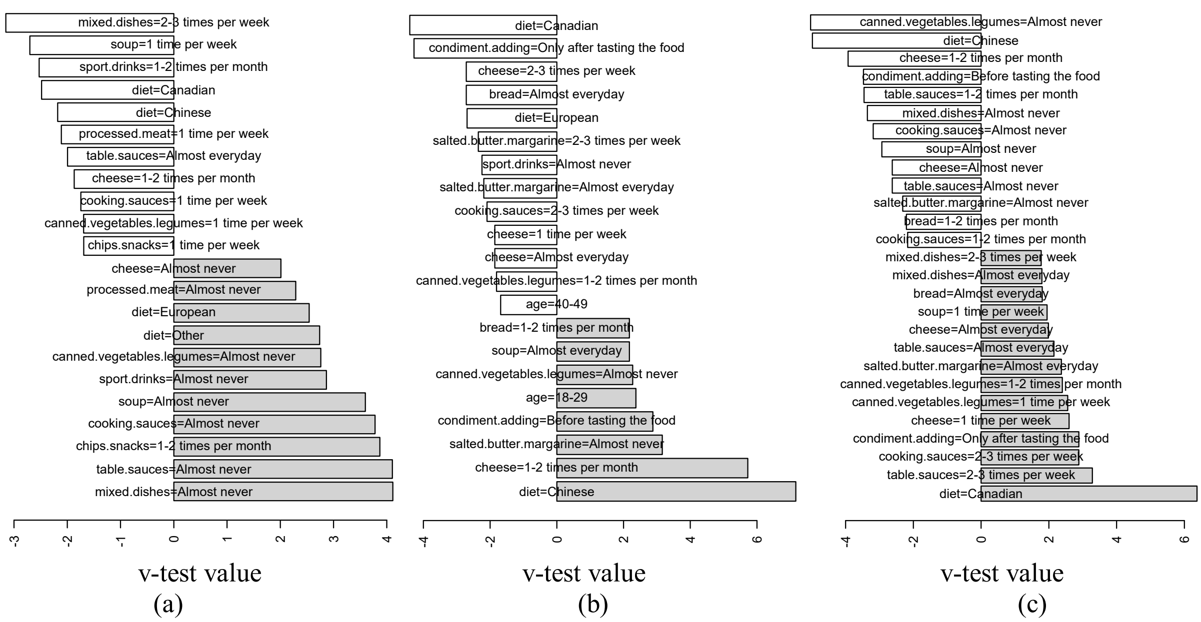


Figure 2.2. Positive and negative associations of consumption frequencies of sodium sources, diet type, habit of salt use at mealtime, demographics and sensory acuity with 3 Dietary Sodium Sources frequency clusters: (a) Low DSS (n=27), (b) Moderate DSS (n=33) and (c) High DSS (n=40).

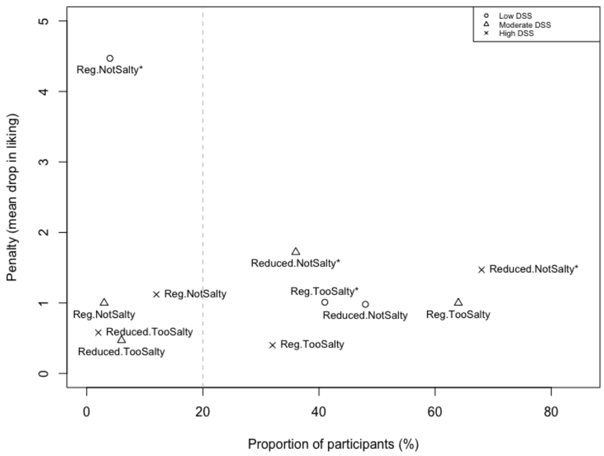
The low DSS cluster (n=27) was positively associated with the consumption of salty chips and snacks at low frequency (*1-2 times per month*) and at *almost never* for 8 of the 13 sodium source groups (mixed dishes, table sauces, cooking sauces, soup, sport drinks, canned vegetables and legumes, processed meat and cheese) based on decreasing order of v-test values (Figure 2.2). This cluster was significantly linked to European and other diets; the majority of the participants of these two diets, 61.5% and 52.2% respectively, belonged to the low DSS cluster.

Conversely, most participants frequently consuming sodium sources such as table sauces, cooking sauces, cheese, canned vegetables and legumes, salted butter and margarine, soup, bread and mixed dishes belonged to the high DSS cluster (n=40). This cluster was negatively associated with infrequent consumption of these foods (*1-2 times per month* or *almost never*). Additionally, the high DSS cluster was linked to Canadian diet; 87.1% of participants who described their diet type as Canadian belonged to this cluster.

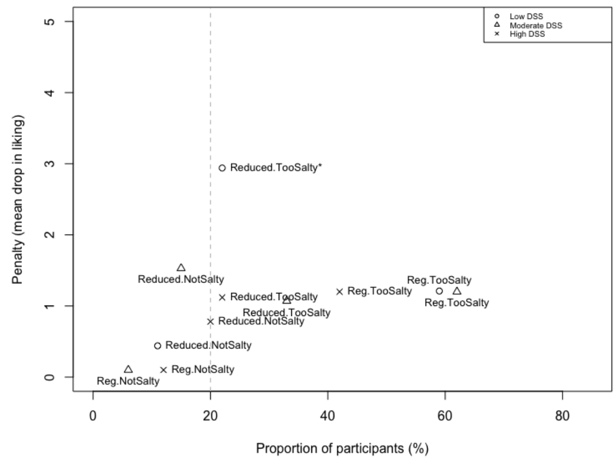
For the moderate DSS cluster (n=33), most participants self-selected Chinese diet. The moderate DSS cluster was significantly associated with the age of 18-29 years old. They consumed most sodium sources at low frequencies or *almost never*; *1-2 times per week* for cheese and bread, *almost never* for salted butter and margarine and canned vegetables and legumes. However, they consumed soup *almost everyday* and usually added salt or condiments to foods before tasting the food at mealtime.

2.3.2.2. Sensory profiles and liking described by consumption frequency of DSS

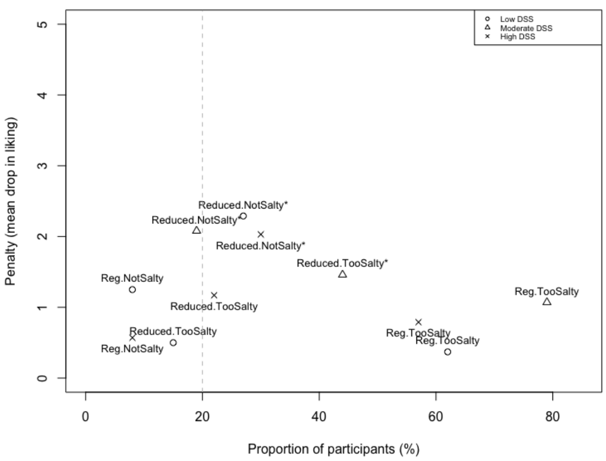
Although comparison of overall liking between regular and sodium-reduced products (Table 2.3) and penalty analysis (Figure 2.3) were performed within each DSS cluster, the number of participants for each cluster was not adequate to make suggestions for product improvement. The liking comparison and penalty analysis for each DSS cluster were used as a tool to identify possible liking drivers for each food product. Therefore, the following results and discussion focus on associations of consumption frequency of DSS with product sensory attribute perception and identification of possible liking drivers; not all penalty analysis results were interpreted.



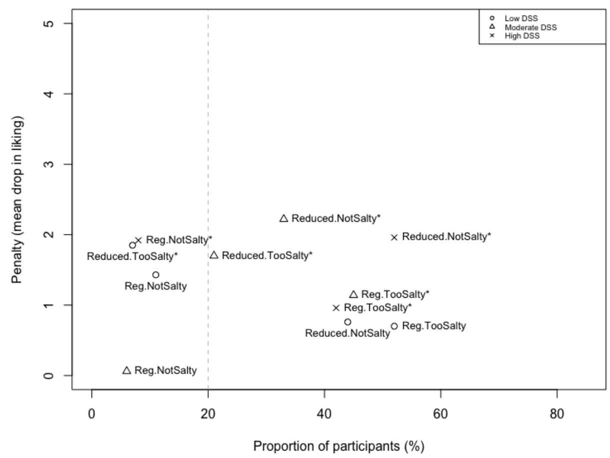
(a)



(b)



(c)



(d)

**: significant non-JAR saltiness categories*

Figure 2.3. Penalty analysis for JAR saltiness and liking of regular (Reg.) and sodium-reduced (Reduced) food products evaluated by 3 Dietary Sodium Sources frequency clusters, Low DSS (n=27), Moderate DSS (n=33) and High DSS (n=40), for (a) potato chips, (b) dill pickles, (c) cooked ham and (d) chicken noodle soup.

Consumption frequency of DSS influenced sensory profiles inconsistently across products. Similar to results for all participants, each DSS cluster perceived regular products as *saltier* than sodium-reduced products. Additionally, the regular ham was perceived with more *seasoning*, the regular soup was perceived as greater in all evaluated attributes except *umami* (Table 2.3). However, there were several differences in detection of sensory differences between the regular and sodium-reduced food across DSS frequency clusters and food products. High DSS participants perceived regular chips as more *flavorful*, regular pickles as less *garlic* and regular soup as more *umami*. Moderate DSS participants perceived regular chips as *oilier* and regular pickles as less *crunchy*. Low DSS participants perceived regular ham as *juicier* and less *tough* and regular pickles as *sourer*.

There were no differences in liking between the regular and sodium-reduced products in any DSS frequency clusters except the high DSS participant preference for the regular compared to the sodium-reduced soup. The single consumer segment of high DSS perceived the regular soup as more *umami* than the sodium-reduced soup and liked the regular soup more. This suggested that umami was a possible key liking driver of soup.

When penalty analysis for saltiness was applied to overall product liking within each DSS frequency consumption cluster, differences were observed among DSS clusters and food products. In addition to *salty*, *oily* and *flavorful* were possible key liking drivers of potato chips. For penalty analysis of potato chips, there were 3 significant non-JAR categories with a substantial (>20%) proportion of participants (Figure 2.3a); low DSS participants perceived regular chips as *too salty* while both moderate and high DSS participants perceived sodium-reduced chips as *not salty enough*. These significant non-JAR categories suggested that lower saltiness of chips significantly associated with lower liking of sodium-reduced chips by high and moderate DSS participants, but greater liking of them for low DSS participants**.** Moreover, compared to low DSS participants, moderate DSS and high DSS participants perceived a greater number of attribute differences between regular and sodium-reduced potato chips. Moderate DSS participants perceived regular chips as *oilier* and had no preferences for regular and sodium-reduced chips. *Oily* may be an undesirable attribute contributing to potato chip preference for moderate DSS participants. High DSS participants perceived the regular chips as more *flavorful*. The mean liking of sodium-reduced chips was greater than that of regular chips for low (6.9 vs. 7.0 respectively) and moderate (6.3 vs. 6.8) DSS participants, but an opposing result was observed for high DSS participants (7.0 vs. 6.6). Therefore, the decrease in *flavorful* due to sodium reduction may decrease liking of potato chips for high DSS participants.

2.4. Discussion

Sodium-reduced commercially available formulations of the food products evaluated in this study were perceived to be different from their conventional counterparts in not only salt intensity but other sensory attributes as well. The number of sensory attribute changes were different across food products. The difference in sensory attributes may be due to flavor interactions and/or ingredient changes required for food reformulation. Potato chips with sodium reduction, and sodium-reduced pickles and ham with the use of potassium chloride (Table 2.2) were perceived as less intense in saltiness and several sensory attributes compared to the regular products. However, the sodium reduction reformulation with changes in several ingredients lead to changes in all evaluated attributes of chicken noodle soup.

The decreased intensity of all evaluated sensory attributes of the sodium-reduced soup compared to the regular was associated with a decrease in consumer acceptance. Penalty analysis suggested perceived saltiness significantly influenced liking of all evaluated products. However, saltiness was a key liking driver for only dill pickles; saltiness decrease contributed to an increase in pickle liking for all participants. In addition to the contribution of salty taste to product preference, the changes in other sensory attributes were also important to the preference of other evaluated products. The decreased intensity in saltiness and several sensory attributes in sodium-reduced chips and ham did not change overall liking, suggesting that the sensory differences were acceptable to participants and these attributes were not key liking drivers. Other sensory attributes with unchanged intensities may play a more important role for consumer acceptance of sodium-reduced potato chips and ham. Moreover, groups within the population responded differently to sodium reduction of food products; lower saltiness decreased product liking for some participants but increased it for others. These opposing perceptions may contribute to non-significant differences in mean liking between the regular and sodium-reduced chips and ham assessed by all participants.

As suggested by Lawless, Patel, & Lopez (2016), penalty analysis in the current study provided insights in consumer testing for sodium-reduced food products as liking drivers and consumer segmentation. Perceived saltiness was not consistently a unique key liking driver for significant sodium food sources. Salt reduction without changes in the intensity of liking drivers could be acceptable to consumers. Therefore, identification of key attributes that drive consumer liking is necessary for food manufacturers to successfully reformulate sodium-reduced food products. Regarding consumer segmentation, penalty analysis also suggested that there may be opposing groups whose liking decreases or increases along with reduced saltiness. These opposing JAR opinions confirmed the need to segment consumers based on their perception influences, which was also one of the current study objectives.

Limited data are available in the literature regarding differences in sensory profiles and preference between the regular and sodium-reduced products evaluated in this study. Reformulated cooked ham is reported to be not different in sensory characteristics and acceptable to consumers at a range of sodium reduction levels depending on the salt replacers used to achieve the sodium reduction (Inguglia et al., 2017; Jaenke et al., 2017). Sodium plays an important role in water holding capacity of meat protein, which results in acceptable texture characteristics of a meat product (Inguglia et al., 2017). Therefore, sodium-reduction leads to changes in sensory characteristics of cooked ham, especially texture attributes, i.e. ham of different salt levels with the use of salt replacers evaluated by trained panelists (Gaudette & Pietrasik, 2017; Greiff et al., 2015) or without the use of salt replacers evaluated by untrained panelists (Delgado-Pando et al., 2018). In the current study, consumers detected the difference between commercial regular and sodium-reduced hams in only one texture attribute, *juiciness* of ham. Similar to the current study, Pietrasik & Gaudette (2014) reported no preference difference for regular and 30% sodium-reduced cooked ham.

Willems et al. (2011) reported similar results for preference of chicken noodle soup; the 22%- and 32%-sodium-reduced chicken noodle soups were less liked than the regular-salt soup by 646 French consumers. It is suggested that 48% sodium reduction is possible in chicken broth with the addition of up to 0.75% KCl without significant impact to basic tastes (Hooge & Chambers, 2010). The ingredients of the current sodium-reduced soup differed from the regular soup, which likely lead to the difference in many sensory characteristics. Moreover, saltiness of chicken soup was reported to be affected by thickeners and positively correlated with chicken and overall flavors (Rosett, Hamill, Morris, & Klein, 1997; Rosett, Kendregan, Gao, Schmidt, & Klein, 1996). Therefore, a 25% sodium reduction and ingredient differences in the current soup (Table 2) lead to perceptible changes in the sensory profile and contributed to the decreased liking of the sodium-reduced product.

Trained panelists have been used in most previous studies to compare salt perception or sensory profiles between regular and sodium-reduced foods, i.e. meat products including cooked ham (Barbieri, Barbieri, Bergamaschi, Francheschini, & Berizi, 2016; Gaudette & Pietrasik, 2017; Greiff et al., 2015). Descriptive consumer methods have been also applied to profiling of sodium-reduced foods; i.e. Free Listing for dry fermented sausages (Dos Santos et al., 2015) and cheese (Costa et al., 2018), Check-All-That-Apply (CATA) for bread (Antúnez et al., 2017, 2016), dry fermented sausages (Dos Santos et al., 2015) and cooked ham (Henrique et al., 2015), Flash Profile (FP) for puff pastry (Silow, Zannini, et al., 2016), Ranking Descriptive Analysis (RDA) with consumers for white pudding (Fellendorf et al., 2015, 2016) and cured meat products (Delgado-Pando et al., 2018). The experimental research samples with tailored sodium levels were differentiated by these consumer methods. In contrast, we used RATA with consumers to compare descriptive profiles of commercial regular and sodium-reduced food products; products in which differences are minimized to be acceptable to consumers. Among rapid descriptive consumer methods, RATA generates more powerful information with intensity values compared with the aforementioned methods (Vidal, Ares, Hedderley, Meyners, & Jaeger, 2016). The 3-point RATA scale was appropriate for sensory profiling of regular and sodium-reduced food products; sensory differences between regular and sodium-reduced products were detected by a consumer panel through a single tasting task.

We studied a variety of sodium-reduced food products available in the marketplace. The comparisons across these products are useful for generalization of our study findings. However, the use of commercial products limits further discussion to describe the influence of processing and ingredients on product sensory changes. Additionally, several staple food items contributing to substantial dietary sodium, i.e. breads and dairy products, are not available in the Canadian market. The further application of our study methods to other food items as research formulations or possible available products in other countries are helpful for the global food industry to meet sodium reduction targets.

Although convenience sampling at a university was used to recruit participants, the consumer sample was appropriate for evaluation of sodium-reduced food products. The participant ethnicities, revealed through diet type data, are representative of ethnocultural diversity in Canada. Canada has a foreign-born population (20.6% in 2011, obtained by National Household Survey) with the largest source from Asia and increased share of immigrants from Africa, the Caribbean, Central and South America. Moreover, most participants were young adults (68% aged 18-29 yrs), who are potential target consumers for sodium-reduced food products to avoid sodium intake associated with health detriments observed at middle age and older.

We observed that sub groups within the study population responded differently to sodium reduction in processed foods, as did Antúnez, Giménez, Alcaire, Vidal, & Ares (2019), confirming the food industry challenge to please every consumer with a single formulation. While previous studies of sodium-reduced processed foods focused on consumer sensory perception and/or preference, and a limited number of studies have considered inter-individual differences in consumers' hedonic reaction towards sodium reduction (Antúnez et al., 2019; Bobowski et al., 2015), the current study additionally examined associations of consumer inter-individual differences with product sensory attribute perception and liking. We observed that DSS consumption frequency influenced perception of product sensory attributes; sensory differences between regular and sodium-reduced foods were perceived differently across DSS clusters. Possible drivers of liking were identified across clusters, i.e. *flavorful* of potato chips and *umami* of chicken noodle soup for the segment of consumers who frequently consumed dietary sodium sources. The greater *flavorful* and *umami* intensity, in regular chips and soup respectively, compared to the sodium-reduced products was detected only by the high DSS participants. The lower *flavorful* intensity in the sodium-reduced chips may come from the decrease of appetitive flavors associated with salty as suggested by Liem et al. (2011). Lioe, Apriyantono, Takara, Wada, & Yasuda (2005) reported that greater concentration of sodium chloride increased umami taste of a monosodium glutamate solution when examining the taste intensity of binary tastant mixtures. The current finding is aligned with the suggestion of Miyaki, Retiveau-Krogmann, Byrnes, & Takehana (2016) that enhanced umami is associated with greater consumer acceptance of sodium-reduced chicken noodle soup. Similarly, sodium-reduced chips were perceived as less *oily* than regular chips by the moderate DSS consumption frequency cluster, but this attribute may be an undesirable attribute for moderate DSS participants.

It is evident that usual consumption frequency of DSS influences intensity perception of salt taste and other attributes in foods, and unique liking drivers are identified for different consumer segments. Although consumers are largely aware of the negative health effects of high salt intake (Newson et al., 2013), it is difficult for them to reduce salt in their diet. Consumers add salt to foods at the table if food products are lower in salt intensity than desired (Liem, Miremadi, et al., 2012). Therefore, it is necessary to consider the usual sodium intake as well as consumption habit of the target market segment for successful reformulation of sodium-reduced foods. Moreover, gradual sodium reduction could be the most notable strategy, which enables consumers to adapt to increasing levels of sodium reduction in foods (Bobowski et al., 2015; Willems et al., 2013) and to be gradually merged into a single target segment through their decreasing sodium intake.

For assessment of sodium food source consumption and dietary habits, we suggested the use of the DSS-FFQ, an online food frequency questionnaire that includes 15 multiple-choice questions regarding food consumption frequencies, diet type and habitual salt use at mealtime. The DSS-FFQ was used to stratify participants by consumption frequency of 'dietary sodium sources' as DSS segments (low, moderate, high). The use of online questionnaires is inexpensive and convenient for data collection from broad geographic areas (Boeckner, Pullen, Walker, Abbott, & Block, 2002); FFQ could be developed specifically for populations of interest, with culturally appropriate foods and age groups. The DSS-FFQ could be adapted for use with populations in other industrialised countries, where 70-80% of dietary sodium come from processed foods (Health Canada, 2018b; Kloss et al., 2015). However, a study with a larger sample size is necessary to validate the DSS-FFQ for its future applications. In contrast, in developing countries, the majority of dietary sodium comes from cooking or at the table (Kloss et al., 2015). In order to apply the DSS-FFQ to consumer studies in developing countries, adaptation of frequency scales and additional questions about traditional foods and cooking habits may be helpful (Ponce-Martínez et al., 2018; Rios-Leyvraz et al., 2018).

Although it is reported that individual differences in taste perception and sensitivity may associate with consumer perception and food preference (Köster & Mojet, 2018; Sandell, Hoppu, & Laaksonen, 2018), no associations were observed in this study. A majority of supertasters perceived regular products as too salty, and they perceived greater intensities in various sensory attributes compared to tasters and non-tasters (results not shown); however, no conclusions were made as the taster group sample sizes were dissimilar and small for taster and non-taster groups (Table 2.1). Previously, it is reported that supertasters perceived greater saltiness, greater sensory and/or liking changes to increasing sodium levels in cheese and chicken broth (Hayes et al., 2010). There were no relationships between individual salt detection threshold with sensory attribute perception and liking, but DSS group threshold values increased along with the increasing consumption frequency of DSS. The sodium chloride threshold values in this study were comparable with the salt detection threshold values reported by Mitchell, Brunton, & Wilkinson (2013), 10.03 ± 0.78 mM among 60 consumers (34 females) in Ireland. Previous studies reported similar findings for the lack of association between individual sodium detection threshold with the salt taste perception and/or liking (Lucas et al., 2011; Mitchell et al., 2013). Larger sample sizes for three DSS clusters will be needed to assess thresholds representative for different DSS populations, then to explore the relationships of threshold with DSS, sensory attribute perception and liking. Among inter-individual differences, health status may be a significant influence for consumers who have health problems exacerbated by high sodium intake such as high blood pressure, heart disease and stroke (Mente et al., 2018). Further studies on sensory perception and preference of sodium-reduced food products for health-focused consumer segments will guide the food industry in successful reformulation of sodium-reduced food towards specific target consumer segments.

2.5. Conclusions

Commercially available sodium-reduced food products and their regular counterparts were perceived by consumers to differ not only in salty taste but also in other product sensory attributes, such as *oily* and *flavorful* for potato chips, *garlic* for dill pickles; *seasoning* and *juicy* for ham; *umami, chicken broth, seasoning, flavorful* and *oily* for chicken noodle soup. These changes were acceptable to consumers. There were no changes in liking for potato chips and ham, but perceived sensory attribute changes contributed to a decrease in overall liking for soup and an increase in liking for pickles. Consumption frequency of DSS influenced product sensory perception in different ways across food products. Consumption frequency of DSS was a significant contributor to consumer preference for soup, but not for chips, pickles and ham. Saltiness was a key driver of pickle liking. In addition to salty taste, changes in other attributes may decrease product liking, such as *umami* for soup, *oily* and *flavorful* for chips. Product sensory attribute perception and consumer acceptance are important contributors to success in reformulation of processed foods for sodium reduction. The current findings and their application to other food products can aid successful development of sodium-reduced foods.

2.6. References

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2017). Consumer perception of salt-reduced breads: Comparison of single and two-bites evaluation. *Food Research International*, *100*(July), 254–259. https://doi.org/10.1016/j.foodres.2017.07.014

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2019). Consumers' heterogeneity towards salt reduction: Insights from a case study with white rice. *Food Research International*, *121*(March), 48–56. https://doi.org/10.1016/j.foodres.2019.03.007

Antúnez, L., Giménez, A., & Ares, G. (2016). A consumer-based approach to salt reduction: Case study with bread. *Food Research International*, *90*, 66–72. https://doi.org/10.1016/j.foodres.2016.10.015

Arcand, J., Jefferson, K., Schermel, A., Shah, F., Trang, S., Kutlesa, D., … Abbe, M. R. L. (2016). Examination of food industry progress in reducing the sodium content of packaged foods in Canada : 2010 to 2013. *Appl. Physiol. Nutr. Metab.*, *41*(April), 1–7. https://doi.org/dx.doi.org/10.1139/apnm-2015-0617

Ares, G., Bruzzone, F., Vidal, L., Cadena, R. S., Giménez, A., Pineau, B., … Jaeger, S. R. (2014). Evaluation of a rating-based variant of check-all-that-apply questions: Rate-all-that-apply (RATA). *Food Quality and Preference*, *36*, 87–95. https://doi.org/10.1016/j.foodqual.2014.03.006

Barbieri, G., Barbieri, G., Bergamaschi, M., Francheschini, M., & Berizi, E. (2016). Reduction of NaCl in cooked ham by modification of the cooking process and addition of seaweed extract (Palmaria palmata). *LWT - Food Science and Technology*, *73*, 700–706. https://doi.org/10.1016/j.lwt.2016.06.057

Bartoshuk, L. M., Duffy, V. B., & Miller, I. J. (1994). PTC/PROP tasting: Anatomy, psychophysics, and sex effects. *Physiology and Behavior*, *56*(6), 1165–1171. https://doi.org/10.1016/0031-9384(94)90361-1

Bobowski, N., Rendahl, A., & Vickers, Z. (2015). A longitudinal comparison of two salt reduction strategies: Acceptability of a low sodium food depends on the consumer. *Food Quality and Preference*, *40*(PB), 270–278. https://doi.org/10.1016/j.foodqual.2014.07.019

Boeckner, L. S., Pullen, C. H., Walker, S. N., Abbott, G. W., & Block, T. (2002). Use and reliability of the World Wide Web version of the block health habits and history questionnaire with older rural women. *Journal of Nutrition Education and Behavior*, 20–24. https://doi.org/10.1016/S1499-4046(06)60307-2

Cappuccio, F. P., Beer, M., & Strazzullo, P. (2019). Population dietary salt reduction and the risk of cardiovascular disease. A scientific statement from the European Salt Action Network. *Nutrition, Metabolism and Cardiovascular Diseases*, *29*(2), 107–114. https://doi.org/10.1016/j.numecd.2018.11.010

Costa, R. G. B., Alves, R. C., Cruz, A. G. da, Sobral, D., Teodoro, V. A. M., Costa Junior, L. C. G., … Miguel, E. M. (2018). Manufacture of reduced-sodium Coalho cheese by partial replacement of NaCl with KCl. *International Dairy Journal*, *87*, 37–43. https://doi.org/10.1016/j.idairyj.2018.07.012

Delgado-Pando, G., Fischer, E., Allen, P., Kerry, J. P., O'Sullivan, M. G., & Hamill, R. M. (2018). Salt content and minimum acceptable levels in whole-muscle cured meat products. *Meat Science*, *139*(January), 179–186. https://doi.org/10.1016/j.meatsci.2018.01.025

Dos Santos, B. A., Bastianello Campagnol, P. C., da Cruz, A. G., Galvão, M. T. E. L., Monteiro, R. A., Wagner, R., & Pollonio, M. A. R. (2015). Check all that apply and free listing to describe the sensory characteristics of low sodium dry fermented sausages: Comparison with trained panel. *Food Research International*, *76*(Part 3), 725–734. https://doi.org/10.1016/j.foodres.2015.06.035

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding. *Meat Science*, *103*, 75–82. https://doi.org/10.1016/j.meatsci.2014.12.010

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016). Effect of using ingredient replacers on the physicochemical properties and sensory quality of low-salt and low-fat white puddings. *European Food Research and Technology*, *242*(12), 2105–2118. https://doi.org/10.1007/s00217-016-2707-z ER

Fischer, P. W. F., Vigneault, M., Huang, R., Arvaniti, K., & Roach, P. (2009). Sodium food sources in the Canadian diet. *Applied Physiology, Nutrition, and Metabolism*, *34*(5), 884–892. https://doi.org/10.1139/H09-077

Gaudette, N. J., & Pietrasik, Z. (2017). The sensory impact of salt replacers and flavor enhancer in reduced sodium processed meats is matrix dependent. *Journal of Sensory Studies*, *32*(1), 1–11. https://doi.org/10.1111/joss.12247

Graudal, N. A., Hubeck-Graudal, T., & Jürgens, G. (2016). Reduced dietary sodium intake increases heart rate. A meta-analysis of 63 randomized controlled trials including 72 study populations. *Frontiers in Physiology*, *7*(MAR), 1–8. https://doi.org/10.3389/fphys.2016.00111

Greiff, K., Mathiassen, J. R., Misimi, E., Hersleth, M., Aursand, I. G., Ekrem, M., … Aursand, I. G. (2015). Gradual reduction in sodium content in cooked ham, with corresponding change in sensorial properties measured by sensory evaluation and a multimodal Machine vision system. *PLoS ONE*, *10*(9), 1–15. https://doi.org/10.1371/journal.pone.0137805

Hayes, J. E., & Keast, R. S. J. (2011). Two decades of supertasting: Where do we stand? *Physiology and Behavior*, *104*(5), 1072–1074. https://doi.org/10.1016/j.physbeh.2011.08.003

Hayes, J. E., Sullivan, B. S., & Duffy, V. B. (2010). Explaining variability in sodium intake through oral sensory phenotype, salt sensation and liking. *Physiology and Behavior*, *100*(4), 369–380. https://doi.org/10.1016/j.physbeh.2010.03.017

Health Canada. (2018). *Sodium reduction in processed foods in Canada: An evaluation of progress toward voluntary targets from 2012 to 2016*. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/legislation-guidelines/guidance-documents/guidance-food-industry-reducing-sodium-processed-foods-progress-report-2017.html

Henrique, N. A., Deliza, R., & Rosenthal, A. (2015). Consumer Sensory Characterization of Cooked Ham Using the Check-All-That-Apply (CATA) Methodology. *Food Engineering Reviews*, *7*(2), 265–273. https://doi.org/10.1007/s12393-014-9094-7

Hooge, S., & Chambers, D. (2010). A comparison of basic taste modalities, using a descriptive analysis technique, for varying levels of sodium and KCL in two model soup systems. *Journal of Sensory Studies*, *25*(4), 521–535. https://doi.org/10.1111/j.1745-459X.2010.00284.x

Inguglia, E. S., Zhang, Z., Tiwari, B. K., Kerry, J. P., & Burgess, C. M. (2017). Salt reduction strategies in processed meat products – A review. *Trends in Food Science & Technology*, *59*, 70–78. https://doi.org/10.1016/j.tifs.2016.10.016

ISO. (2011). *ISO 3972: Sensory analysis - Methology - Method of investigating sensitivity of taste*. *INTERNATIONAL STANDARD ISO*.

Israr, T., Rakha, A., Sohail, M., Rashid, S., & Shehzad, A. (2016). Salt reduction in baked products: Strategies and constraints. *Trends in Food Science and Technology*, *51*, 98–105. https://doi.org/10.1016/j.tifs.2016.03.002

Jaenke, R., Barzi, F., McMahon, E., Webster, J., & Brimblecombe, J. (2017). Consumer acceptance of reformulated food products: A systematic review and meta-analysis of salt-reduced foods. *Critical Reviews in Food Science and Nutrition*, *57*(16), 3357–3372. https://doi.org/10.1080/10408398.2015.1118009

Kloss, L., Meyer, J. D., Graeve, L., & Vetter, W. (2015). Sodium intake and its reduction by food reformulation in the European Union - A review. *NFS Journal*, *1*, 9–19. https://doi.org/10.1016/j.nfs.2015.03.001

Köster, E., & Mojet, J. (2018). Complexity of consumer perception. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 1* (Vol. 1, pp. 23–45). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102089-0.00002-9

Lawless, H. T., Patel, A. A., & Lopez, N. V. (2016). Mixed messages: Ambiguous penalty information in modified restaurant menu items. *Food Quality and Preference*, *52*, 232–236. https://doi.org/10.1016/j.foodqual.2016.05.005

Lê, S., Josse, J., & Husson, F. (2008). FactoMineR : An R package for multivariate analysis. *Journal of Statistical Software*, *25*(1), 253–258. https://doi.org/10.18637/jss.v025.i01

Liem, D. G., Miremadi, F., & Keast, R. S. J. (2011). Reducing sodium in foods: The effect on flavor. *Nutrients*. https://doi.org/10.3390/nu3060694

Liem, D. G., Miremadi, F., Zandstra, E. H., & Keast, R. S. (2012). Health labelling can influence taste perception and use of table salt for reduced-sodium products. *Public Health Nutrition*, *15*(12), 2340–2347. https://doi.org/10.1017/s136898001200064x

Lioe, H., Apriyantono, A., Takara, K., Wada, K., & Yasuda, M. (2005). Umami taste enhancement of MSG/NaCl mixtures by subthreshold L-a-aromatic amino acids. *Journal of Food Science*, *70*, S401–S405.

Lucas, L., Riddell, L., Liem, D. G., Whitelock, S., & Keast, R. (2011). The influence of sodium on liking and consumption of salty food. *Journal of Food Science*, *76*(1). https://doi.org/10.1111/j.1750-3841.2010.01939.x

McLean, R. M. (2014). Measuring population sodium intake: A review of methods. *Nutrients*, *6*(11), 4651–4662. https://doi.org/10.3390/nu6114651

Mente, A., O'Donnell, M., Rangarajan, S., McQueen, M., Dagenais, G., Wielgosz, A., … Yusuf, S. (2018). Urinary sodium excretion, blood pressure, cardiovascular disease, and mortality: a community-level prospective epidemiological cohort study. *The Lancet*, *392*(10146), 496–506. https://doi.org/10.1016/S0140-6736(18)31376-X

Meyners, M., Jaeger, S. R., & Ares, G. (2016). On the analysis of Rate-All-That-Apply (RATA) data. *Food Quality and Preference*, *49*, 1–10. https://doi.org/10.1016/j.foodqual.2015.11.003

Mitchell, M., Brunton, N. P., & Wilkinson, M. G. (2013). The influence of salt taste threshold on acceptability and purchase intent of reformulated reduced sodium vegetable soups. *Food Quality and Preference*, *28*(1), 356–360. https://doi.org/10.1016/j.foodqual.2012.11.002

Miyaki, T., Retiveau-Krogmann, A., Byrnes, E., & Takehana, S. (2016). Umami increases consumer ccceptability, and perception of sensory and emotional benefits without compromising health benefit perception. *Journal of Food Science*, *81*(2), S483–S493. https://doi.org/10.1111/1750-3841.13195

Newson, R. S., Elmadfa, I., Biro, G., Cheng, Y., Prakash, V., Rust, P., … Feunekes, G. I. J. (2013). Barriers for progress in salt reduction in the general population. An international study. *Appetite*, *71*, 22–31. https://doi.org/10.1016/j.appet.2013.07.003

Pérez Rodrigo, C., Aranceta, J., Salvador, G., & Varela-Moreiras, G. (2015). Food Frequency Questionnaires. *Nutr Hosp*, *31*, 49–56. https://doi.org/10.3305/nh.2015.31.sup3.8751

Pietrasik, Z., & Gaudette, N. J. (2014). The impact of salt replacers and flavor enhancer on the processing characteristics and consumer acceptance of restructured cooked hams. *Meat Science*, *96*(3), 1165–1170. https://doi.org/10.1016/j.meatsci.2013.11.005

Ponce-Martínez, X., Colin-Ramirez, E., Sánchez-Puerto, P., Rivera-Mancía, S., Cartas-Rosado, R., Infante-Vázquez, O., … Vargas-Barrón, J. (2018). Bread consumption is associated with elevated blood pressure among adults living in Mexico city–A sub-analysis of the Tlalpan 2020 study. *Nutrients*, *10*(12), 1969. https://doi.org/10.3390/nu10121969

Powles, J., Fahimi, S., Micha, R., Khatibzadeh, S., Shi, P., Ezzati, M., … Mozaffarian, D. (2013). Global, regional and national sodium intakes in 1990 and 2010: a systematic analysis of 24 h urinary sodium excretion and dietary surveys worldwide. *BMJ Open*, *3*(12), e003733. https://doi.org/10.1136/bmjopen-2013-003733

R Core Team. (2017). R: A language and environment for statistical computing. *R Foundation for Statistical Computing, Vienna, Austria*. Retrieved from https://www.r-project.org/

Rios-Leyvraz, M., Bovet, P., Bochud, M., Genin, B., Russo, M., Rossier, M. F., … Chiolero, A. (2018). Estimation of salt intake and excretion in children in one region of Switzerland: a cross-sectional study. *European Journal of Nutrition*, *0*(0), 0. https://doi.org/10.1007/s00394-018-1845-4

Rosett, T. R., Hamill, T., Morris, K., & Klein, B. P. (1997). Taste qualities of reduced-sodium soups as affected by serving temperature. *Journal of Food Science*, *62*(2), 421–424. https://doi.org/10.1111/j.1365-2621.1997.tb04017.x

Rosett, T. R., Kendregan, S. L., Gao, Y., Schmidt, S. J., & Klein, B. P. (1996). Thickening agents effects on sodium binding and other taste qualities of soup systems. *Journal of Food Science*, *61*(5), 1099–1104. https://doi.org/10.1111/j.1365-2621.1996.tb10939.x

Sandell, M., Hoppu, U., & Laaksonen, O. (2018). Consumer segmentation based on genetic variation in taste and smell. In *Methods in consumer research, Volume 1: New approaches to classic methods* (Vol. 1, pp. 423–447). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102089-0.00017-0

Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2016). Current status of salt reduction in bread and bakery products – A review. *Journal of Cereal Science*, *72*, 135–145. https://doi.org/10.1016/j.jcs.2016.10.010

Silow, C., Zannini, E., Axel, C., Lynch, K. M., & Arendt, E. K. (2016). Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, *89*, 330–337. https://doi.org/10.1016/j.foodres.2016.08.031

Sodium Working Group Canada. (2010). *Sodium reduction strategy for Canada*. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating/sodium/related-information/reduction-strategy/recommendations-sodium-working-group.html

Vidal, L., Ares, G., Hedderley, D. I., Meyners, M., & Jaeger, S. R. (2016). Comparison of rate-all-that-apply (RATA) and check-all-that-apply (CATA) questions across seven consumer studies. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2016.12.013

Willems, A. A., Van Hout, D. H. A., Zijlstra, N., & Zandstra, E. H. (2013). Effects of salt labelling and repeated in-home consumption on long-term liking of reduced-salt soups. *Public Health Nutrition*, *17*(5), 1130–1137. https://doi.org/10.1017/S1368980013001055

World Health Organization. (2016). *The SHAKE technical package for salt reduction*. Retrieved from http://www.who.int/dietphysicalactivity/publications/shake-salt-habit/en/

Zandstra, E. H., Lion, R. R., & Newson, R. S. (2016). Salt reduction: Moving from consumer awareness to action. *Food Quality and Preference*, *48*, 376–381. https://doi.org/10.1016/j.foodqual.2015.03.005

Zhao, L., Kirkmeyer, S. V., & Tepper, B. J. (2003). A paper screening test to assess genetic taste sensitivity to 6-n-propylthiouracil. *Physiology and Behavior*. https://doi.org/10.1016/S0031-9384(03)00057-X

Chapter 3. Temporal sensory profiles of regular and sodium-reduced foods elicited by Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA)

3.1. Introduction

The majority of dietary sodium in high and upper-middle income countries comes from packaged and prepared foods such as bread and processed cereal products, processed meats, cheese, salty snack foods, condiments and soups (Health Canada, 2018b; Kloss et al., 2015; Monteiro et al., 2017; World Health Organization, 2016) and higher intakes of these sodium sources have been linked to negative health consequences (Powles et al., 2013; World Health Organization, 2016).

The global food industry has made efforts to reduce sodium levels in food products (Arcand et al., 2016) using a range of strategies (Inguglia et al., 2017; Silow, Axel, et al., 2016; Stieger & Van de Velde, 2013). However, the commercial success of sodium-reduced food products is limited as sodium reduction affects not only salty taste but other product sensory attributes (Inguglia et al., 2017; Israr et al., 2016; Liem et al., 2011) that are important contributors to consumer preference and satisfaction with foods (Tuorila & Monteleone, 2009). Multisensory interactions (taste-taste, taste-aroma) and changes in product structures due to sodium reduction contribute to product sensory changes (Busch et al., 2013). The use of sodium substitutes to partially or totally replace sodium may promote undesirable sensory attributes, noticeably bitter and sour tastes (Ares et al., 2016; da Silva et al., 2014; de Souza et al., 2013; Paulsen et al., 2014; Rodrigues, Goncalves, et al., 2014; Ventanas et al., 2010).

Food sensory perception is a dynamic phenomenon, in which perceived sensory attributes change with the in-mouth transformation of the food (Lawless & Heymann, 2010). Sensory data collected using static methods of a single intensity measurement throughout the evaluation may omit relevant information for understanding consumer preferences (Cadena, Vidal, Ares, &

Varela, 2014). Most previous sensory studies of sodium-reduced food products have evaluated static sensory perception or consumer preference rather than temporal sensory perception. However, an increasing number of studies have been published on the temporal sensory profiles of a range of sodium-reduced products, such as sausages and ham (Lorido et al., 2018, 2016; Paulsen et al., 2014; Ventanas et al., 2010), cheese, cream cheese and butter (da Silva et al., 2014; de Souza et al., 2013; Rodrigues, Goncalves, et al., 2014; Silva et al., 2018; Wendin et al., 2000), bread (Antúnez et al., 2018; Ares et al., 2016), and others (Gonçalves et al., 2017; Rodrigues et al., 2016; Rodrigues, Junqueira, et al., 2014). Temporal sensory methods are a useful tool to reveal sensory perception changes during food oral processing of reformulated sodium-reduced foods (Stieger & Van de Velde, 2013).

Among current temporal sensory profiling methods (Castura, 2018), Time Intensity (TI), Temporal Dominance of Sensations (TDS) and Temporal Check-All-That-Apply (TCATA) have been applied to the evaluation of sodium-reduced products. The temporal changes in multiple product sensory attributes can be considered concurrently by TDS and TCATA. TDS was originally proposed as a multi-attribute temporal sensory method that scaled the intensities of a sequence of dominant attributes (Pineau et al., 2009). A variant of TDS (Pineau et al., 2012), in which the dominant attribute is selected without scaling its intensity, has been widely used. TCATA, a more recent temporal method, generates a continuous description of the sensory characteristics concurrently perceived in products (Ares et al., 2016; Castura et al., 2016). Comparison of TDS and TCATA has been discussed across several product categories (Ares et al., 2017, 2015; Esmerino et al., 2017; Nguyen, Næs, & Varela, 2018; Parker, Lopetcharat, & Drake, 2018). The modalities of flavor and texture are perceived by different channels, chemoreceptors and mechanoreceptors respectively (Chen, 2014; Lawless & Heymann, 2010), and selection of the dominant sensory attribute is a complex and product specific task (Varela et al., 2018). Multi-bite or multi-sip evaluations reflect the sensory experience during the usual consumption of food products and offer a realistic temporal sensory perception approach. Studies comparing methods across products are necessary for selection of the most appropriate method to describe and discriminate between regular and sodium-reduced product temporal profiles.

The objectives of this study were (1) to compare temporal sensory profiles between common salty food products available in the marketplace and their sodium-reduced counterparts, and (2) to compare TDS and TCATA temporal sensory profiles of these products, considering single vs. multiple intakes and evaluation across modalities vs. by modality.

3.2. Materials and Methods

3.2.1. Participants

Participants were recruited on the University of Alberta campus (Edmonton, AB, Canada) and were 18+ years of age and regular consumers of the study products. Exclusion criteria included smoking, pregnancy or having a thyroid condition. Interested participants (n=45) each completed basic taste identification, odor identification, food product description and PROP taster status in a single sensory acuity screening session (Hayes & Keast, 2011). The final panel of twenty participants (15 females, 18-49 yrs) was selected based on their above average sensory acuity screening results and availabilities. The study protocol was approved by a Research Ethics Board at the University of Alberta. Participants completed written informed consent and received a gift card in acknowledgement of their time and contribution to the study.

3.2.2. Food samples and preparation

Four pairs of commonly consumed food products were selected to represent a range of regular and sodium-reduced items available in the Canadian marketplace; potato chips, cooked ham, canned corn and cream of mushroom soup. Product information, sodium content and the sample quantity consumed for each evaluation are presented in Table 3.1. Five potato chips for each sample, were served in 162 mL clear plastic cups with lids. Hams were sliced into 0.3x2x4 (cm) pieces; one piece of each ham sample was served in a 162 mL clear plastic cup with a lid. Canned corn was heated and 10 corn kernels were served in 50 mL clear jars with lids. Soup samples were prepared with 2% partly skimmed milk following the manufacturer's instruction and 60 mL samples were served in 125 mL clear jars with lids. Corn and soup samples were kept at 60 ºC in a water bath before serving. Chips and ham were served at room temperature. All samples were blinded with random 3-digit codes. Distilled water and unsalted crackers were provided to cleanse the palate between samples.

3.2.3. Sensory method

3.2.3.1. Generation of descriptors and familiarization of methods to consumers

Participants attended 6 one-hour sessions to generate and select attributes used for the product description, to standardize the tasting protocol and for familiarization with the use of Compusense Cloud (Compusense, Guelph, ON, Canada) on a tablet to generate TDS (Pineau et al., 2009) and TCATA (Castura et al., 2016) temporal sensory profiles. For TDS, they indicated the dominant sensation perceived in the sample at each moment, defined as "the sensation catching their attention, not necessarily the most intense" (Pineau et al., 2009). For TCATA, participants checked the terms from a list to describe sensory attributes that they perceived in the sample at each moment. In this study, it was not necessary to uncheck the terms due to the use of TCATA fading with an 8.0 sec fade time (Ares et al., 2016).

Table 3.1. Product and testing information for evaluation of potato chips, canned corn, cooked ham and cream of mushroom soup.

Product	Brand name (ingredients)	Sodium content	Quantity consumed per evaluation	Serving temperature	Swallow timepoint	Single/Multiple intake evaluation	Evaluation across/by modality
Potato chips	Lay's Classic Chips, PEPSICO, Canada (potatoes, vegetable oil, salt)	330 mg/50 g	1 chip (approximately 1 g)	Ambient	15 sec	Multiple	Across modalities
	Lay's Lightly Salted Chips with 50% less sodium, PEPSICO, Canada (potatoes, vegetable oil, salt)	160 mg/50 g					
Canned corn	Green Giant Niblet Whole Kernel Corn, B&G Foods Inc., Canada (whole kernel corn, water, salt)	240 mg/125 mL	10 kernels	60 ºC	20 sec	Single	Across modalities
	Green Giant Niblet Whole Kernel Corn - 1/3 Less Salt, B&G Foods Inc., Canada (whole kernel corn, water, salt)	110 mg/125 mL					
Cooked ham	Schneiders Olde Fashioned Ham, Maple Leaf Foods Inc., Canada (ham, water, salt, corn syrup solids, potassium lactate, sodium phosphate, sodium diacetate, sodium erythorbate, sodium nitrite, smoke)	490 mg/55 g	0.3x2x4 (cm) (approximately 5 g)	Ambient	25 sec	Single	Across modalities, By modality
	Schneiders Olde Fashioned Ham - 25% Less Sodium, Maple Leaf Foods Inc., Canada (pork, water, corn syrup solids, potassium lactate, salt, potassium chloride, potassium phosphate, carrageenan, sodium diacetate, sodium erythorbate, sodium nitrite, smoke)	370 mg/55 g					
Cream of mushroom soup	Campbell's Cream of Mushroom Soup, Campbell Company of Canada, Canada (water, mushrooms, canola or soybean oil, wheat flour, cream, corn starch, salt, modified milk ingredients, soy protein isolate, monosodium glutamate, tomato paste, spice extract, barley yeast extract, dehydrated garlic)	850 mg/125 mL	10 mL	60 ºC	10 sec	Multiple	Across modalities
	Campbell's Cream of Mushroom Soup - 40% Less Salt, Campbell Company of Canada, Canada (water, mushrooms, modified corn starch, cream (milk), canola or soybean oil, wheat flour, butter milk powder, salt, yeast extract, soy protein isolate, white wine, flavour (contains dried onions, chicken), spice extracts)	470 mg/125 mL					

Table 3.2. Sensory attributes and definitions used in TDS and TCATA evaluations of potato chips, canned corn, cooked ham and cream of mushroom soup. An attribute list was prepared for each product.

Modality	Potato chips	Canned corn	Cooked ham	Cream of mushroom soup	Definition
Flavor	-	-	Bitter	-	Basic taste associated with caffeine solution
	-	-	Metallic	-	Basic taste associated with various metal flavors
	Salty	Salty	Salty	Salty	Basic taste associated with salt
	Sweet	Sweet	Sweet	Sweet	Basic taste associated with sugar
	Umami	-	Umami	Umami	Basic taste associated with glutamate, salts of amino acids and other molecules called nucleotides
	-	Cooked	-	-	A non-specific flavor associated with the process of heating/cooking
	-	Corn	-	-	Flavor associated to corn
	-	-	-	Cream flavor	A sweet, dairy flavor associated with cream or other high fat dairy products
	-	-	Ham	-	Flavor associated with processed products that contain curing agents (nitrites, sugars, salts)
	Heated oil	-	-	-	Flavor associated with oil heated to a high temperature
	-	-	-	Mushroom	Flavor associated with cooked mushroom
	Potato	-	-	-	Flavor associated with cooked potato
	-	-	-	Seasoning	Flavor associated with seasoning
	-	-	Smoky	-	Dry, dusty flavor of burning wood
	-	Starchy	-	Starchy	Flavor associated with starch
Texture	-	-	Chewy	-	Sensation associated with cohesiveness and to the length of time or the number of chews required to masticate a solid product into a state ready for swallowing
	-	-	-	Creamy	Sensation of creaminess, described as a full, fatty or smooth mouthfeel
	Crispy	-	-	-	Sensation of crispiness, described as the force required to bite while causing a high sound
	-	Crunchy	-	-	Sensation associated with which a sample crumbles, cracks, or shatters
	Dissolving	-	-	-	Sensation caused by moisture absorption and dissolving
	Dry	-	-	-	Sensation of dryness, due to the absence of water or a lack of saliva
	-	Fibrous	Fibrous	-	Sensation refers to long particles oriented in the same direction
	Greasy	-	Greasy	-	Sensation reflects the perception of exuding fat
	-	Juicy	Juicy	-	Sensation caused by higher levels of juices
	-	-	Tender	-	Sensation of tenderness, associated with the ease to chew samples
	-	-	-	Thick	Sensation of thickness, associated with products with a high viscosity
	-	-	-	Thin	Sensation of thinness, associated with products with a low viscosity

Evaluation across the modalities of flavor and texture was used for all study products. Attribute lists included flavor and texture descriptors (Table 3.2) and were the same for TDS and TCATA evaluations. The number of attributes, from 8 to 12, aligned with recommendations in the literature (Castura, 2018; Jaeger et al., 2018; Pineau et al., 2012). Participants placed the entire sample in the mouth for a 60 sec evaluation. Swallowing timepoints for each evaluation are presented in Table 3.1. Participants were instructed to chew the sample as normal and swallow when the message "Swallow" displayed on the screen. Evaluation by modality was additionally carried out for ham. Each ham sample was evaluated three times using different attribute lists; flavor, texture, and combination of flavor and texture. Single-intake evaluation was used for corn and ham while multi-intake evaluation was used for chips (5 bites) and soup (5 sips).

3.2.3.2. Evaluation sessions

Within-subject experimental designs were used; each participant assessed temporal sensory profiles of all study products using both TDS and TCATA in triplicate. TDS and TCATA evaluations were completed on different days; two study samples and one warm-up sample for each of 4 products were evaluated on each day. Participants were asked to wait at least 1 min between samples and take a 5-min break between products, which was managed by a timer on the screen. The order of attributes in the attribute list, the sample orders for each product and the orders of product types were balanced among participants using Williams' Latin square designs.

3.2.4. Data analysis

To remove individual differences in mastication rates, the data from each participant in each replicate (judgement) was standardized according to individual mastication durations; timing began when the first attribute was selected (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009). TDS data were analyzed as recommended by Pineau et al. (2009). TCATA data were analyzed as recommended by Castura et al. (2016). All data analyses were carried out using R version 3.4.1

(R Core Team, 2017). TDS and TCATA curves (dominance rates against time for TDS and citation proportions against time for TCATA), and product trajectories for multi-intake evaluations of chips and soup were plotted using the *tempR* package (Castura, 2017). Difference curves for pairs of regular and low sodium products were obtained by subtracting their dominance rates or citation proportions. A Fisher exact test was applied at each time point to determine statistical significance from zero ($p \leq 0.05$), and significant difference curves were plotted. To obtain product trajectories, Principle Component Analysis (PCA) was conducted on data frames of mean citation proportions (TCATA) or dominance rates (TDS), in which each row is a Product*Time and each column is an Attribute (Castura, 2017).

3.3. Results

3.3.1. Temporal sensory profiles of regular and sodium-reduced products elicited by TDS and TCATA

In this section, results of TDS and TCATA evaluations across modalities, considering a single intake, are described and compared for all four food products.

3.3.1.1. Potato chips

TDS and TCATA shared the same attributes characterizing each of the regular and sodium-reduced chips. Attributes reaching significant dominant rates and citation proportions of more than 50% were *crispy, salty, dissolving, potato* and *heated oil* for the regular chips, and *crispy, dry, potato, dissolving* and *heated oil* for the sodium-reduced chips (Figure 3.1a, b). The highest dominant rates in TDS evaluations and the highest citation proportions in TCATA evaluations revealed that regular chips were characterized the most by *crispy* in early evaluation, *salty* in mid evaluation and *potato* in late evaluation while sodium-reduced chips were characterized by *crispy* initially, followed by *potato* (Figure 3.1a, b). Additionally, *dissolving* reached the highest dominance rate within 25% to 40% of the evaluation time of the regular chips. Of the second most noticeable attributes in TDS and the second highest cited attributes in TCATA, regular chips were characterized by *salty* in early evaluation, and *heated oil* and *salty* in late evaluation while sodium-reduced chips were characterized by *dry, dissolving* and *heated oil* in early, mid and late evaluation, respectively. TCATA provided a more detailed description of concurrent attributes for some timepoints; for example, *dissolving* and *heated oil* had comparable citation proportions near the mid evaluation in TCATA profiles, but *dissolving*, not *heated oil*, was significantly dominant at the same timepoint in TDS profiles.

Significant difference curves (Figure 3.1c) reveal that regular chips were characterized by *salty* by more judgements than sodium-reduced chips throughout the evaluation time while sodium-reduced chips were characterized by *dry* by more judgements than regular chips within early-to mid evaluation. While TDS detected many attribute differences in dominance rates (*salty*, *crispy*, *dry*, *greasy*, *potato*, *sweet*, *umami*), there were 2 attributes that were significantly different in citation proportions for TCATA evaluations (*salty*, *dry*) (Figure 3.1c). A greater dominance rate/citation proportion of *crispy* at the beginning of evaluations in sodium-reduced chips than in regular chips suggested that *crispy* was more noticeable in sodium-reduced chips than in regular chips. However, the significant difference in *crispy* was observed in significant difference curves for TDS but not TCATA. Although *dry* was perceived by fewer judgements than *crispy*, it was a significant dominant attribute in early TDS evaluations of sodium-reduced chips (Figure 3.1b, left), perceived by more judgements (Figure 3.1c, right) and was more noticeable (Figure 3.1c, left) in the sodium-reduced than regular chips.

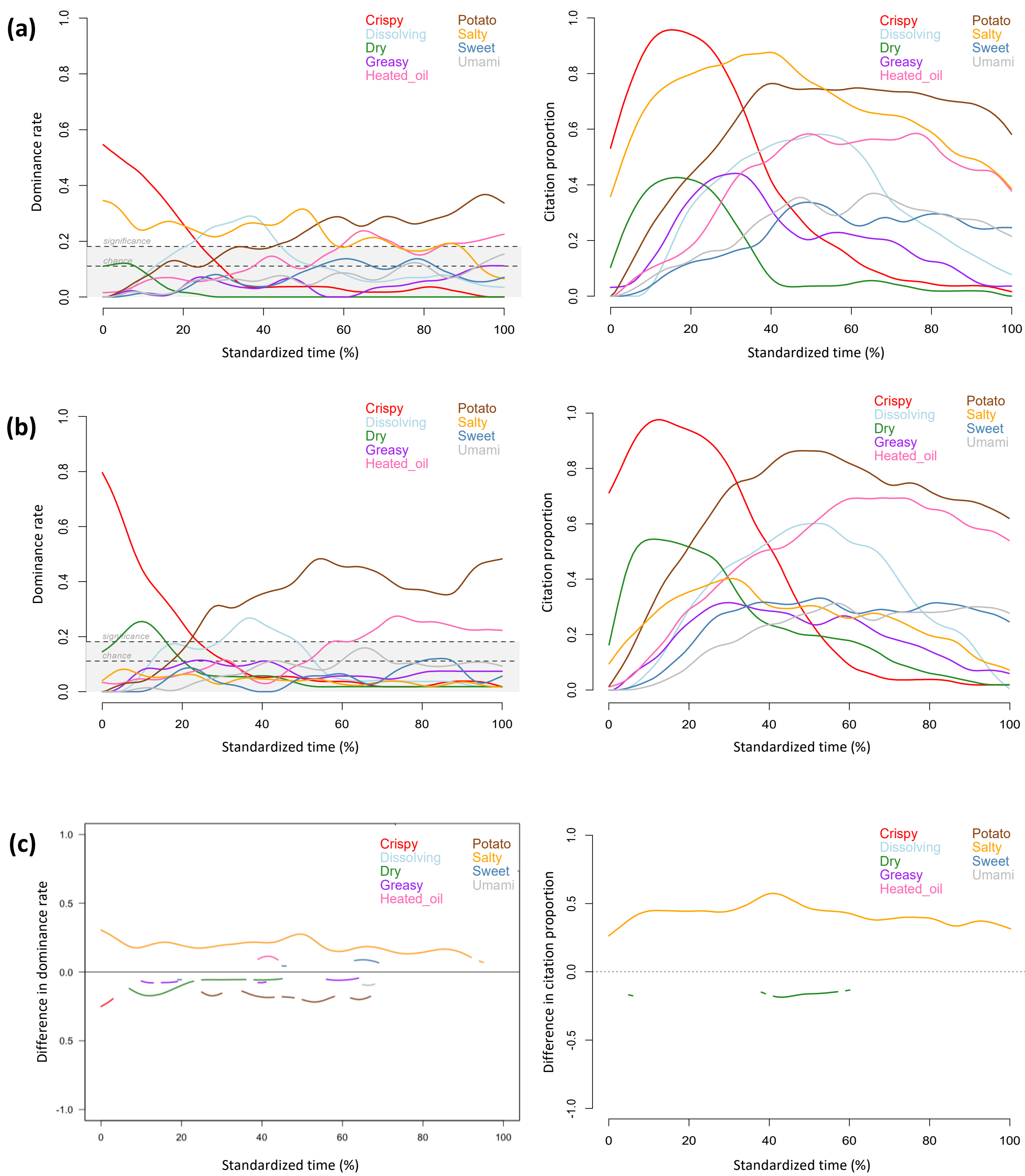


Figure 3.1. Temporal profiles for regular (a) and sodium-reduced (b) chips, and significant difference curves (c) obtained by TDS (left) and TCATA (right) evaluations of the first intake (n=54).

3.3.1.2. Canned corn

Crunchy, juicy, fibrous, sweet and *corn* were the significant dominant attributes in TDS profiles of both the regular and sodium-reduced corn; these attributes were also the most cited attributes in TCATA profiles throughout the evaluation (Figure 3.2a, b). Additionally, the *cooked* attribute of regular corn and the *cooked* and *salty* attributes of sodium-reduced corn reached citation proportions of more than 50% in TCATA profiles. TDS and TCATA profiles of regular and sodium-reduced corn (Figure 3.2) shared some similarities for the most noticeable/cited attributes over evaluation time; *crunchy* at the beginning, *sweet* near mid evaluation, and *corn* during the second half of the evaluation.

Similar to the results for potato chips, several attributes had comparable citation proportions in TCATA, but one attribute was significantly dominant over the other attributes in TDS at the same time point. In early evaluation of sodium-reduced corn, *juicy*, *corn* and *sweet* were sequentially dominant in TDS and had comparable citation proportions in TCATA. In mid evaluation of sodium-reduced corn, *corn* was the most dominant attribute, *fibrous* was the second dominant attribute, and *sweet* was not significantly dominant in TDS; all three attributes had comparable citation proportions in TCATA.

As shown in Figure 3.2c, TDS detected significant differences in dominance rates between regular and sodium-reduced corn for a larger number of attributes but in shorter periods of time than TCATA. When using TCATA, the single attribute for which significant differences between products were identified was *salty*. Although *salty* was not significantly dominant in TDS evaluations (area under significant level in Figure 3.2, a and b, left), both TDS and TCATA significant difference curves indicated that the sodium-reduced corn was characterized by *salty* by more judgements than regular corn at several timepoints (brown lines in Figure 3.2c). Among attributes having significant dominance rates in TDS profiles, *sweet* was more significantly noticeable in regular than sodium-reduced corn. However, the citation proportions of *sweet* were comparable in TCATA profiles of regular and sodium-reduced corn.

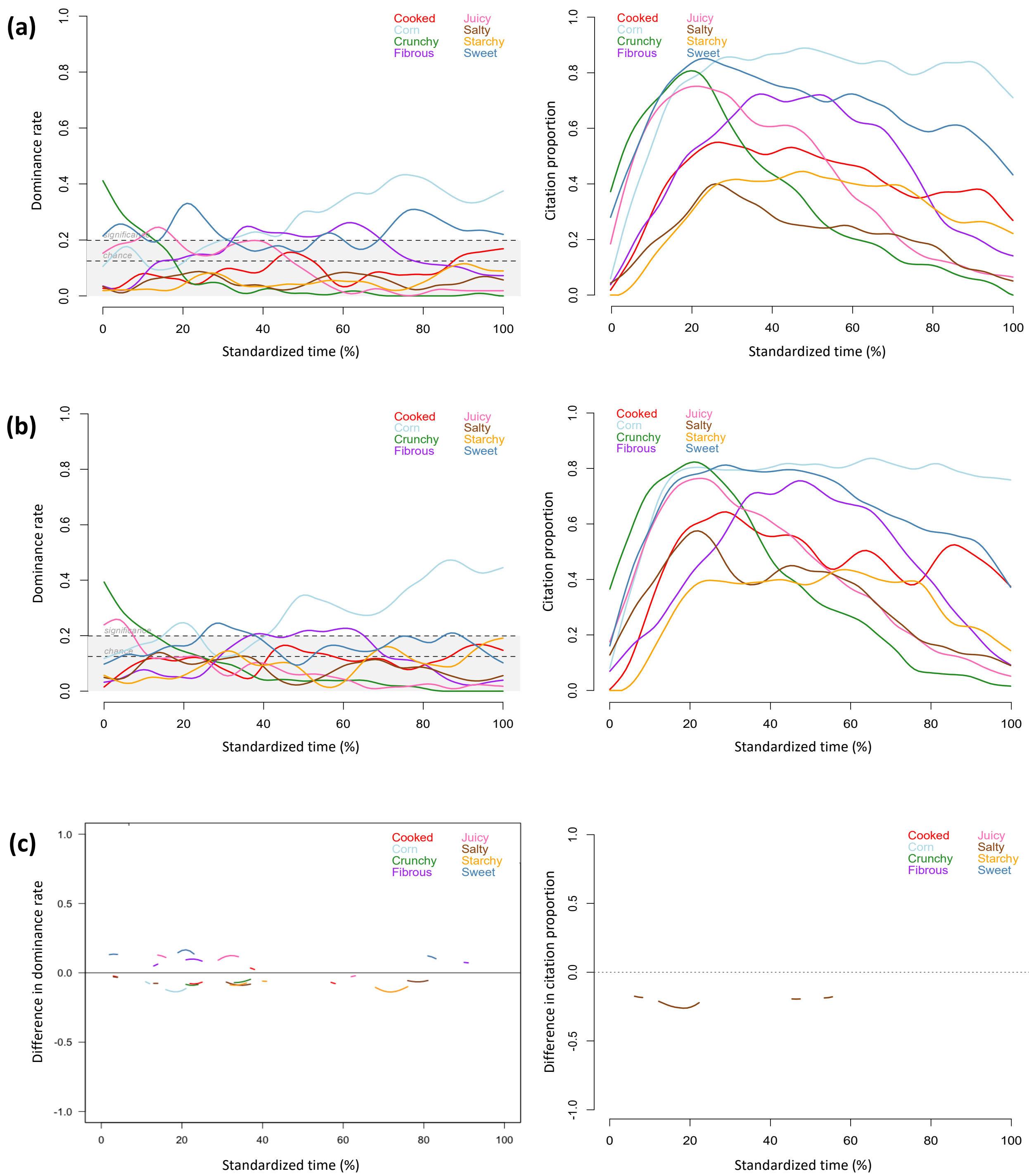


Figure 3.2. Temporal profiles for regular (a) and sodium-reduced (b) corn, and significant difference curves (c) obtained by TDS (left) and TCATA (right) (n=54).

3.3.1.3. Cooked ham

In TDS and TCATA across modalities, where flavor and texture attributes were combined in one attribute list, attributes of both hams exhibited different temporal patterns, with greater variation between regular and sodium-reduced hams in TDS evaluations than in TCATA (Figure 3.3a and Figure 3.4a). *Salty* and *ham* were the most cited attributes as well as significantly dominant attributes in both the regular and sodium-reduced hams for the majority of the evaluation time. Although *smoky* was highly cited throughout TCATA evaluation of regular and sodium-reduced hams, and comparable to *salty* and *ham* at several timepoints (Figure 3.4a), it reached the significant dominance rate only in the regular ham in short durations (several seconds) at 45% and 80% of evaluation time (Figure 3.3a, left).

TCATA curves of *juicy*, *smoky*, and *bitter* differed between regular and sodium-reduced ham; *smoky* shared the highest citation proportion with *salty* and *ham* at around 20% of evaluation time in the sodium-reduced ham, *juicy* reached a citation proportion of more than 60% with high slope at about 30% of evaluation time, and *bitter* was perceived by more judgements throughout the evaluation in the sodium-reduced than regular ham (Figure 3.4a). Both regular and sodium-reduced ham were characterized by *ham*, *salty*, *smoky*, *umami* and *metallic* in late TCATA evaluation; citation proportions of *metallic* and *umami* were increasing and reached comparable values to decreasing citation proportions of *salty*, *ham* and *smoky* in both regular and sodium-reduced ham by the end of evaluation.

At the beginning of TDS evaluations, *salty* was the most noticeable attribute in regular ham while *chewy* was the most noticeable attribute in sodium-reduced ham. *Salty* was the most noticeable attribute in mid evaluation of both regular and sodium-reduced ham, with a higher dominance rate in the regular than sodium-reduced ham. TDS profiles revealed the differences in dominant attributes in late evaluation; *metallic* had a higher dominance rate in a longer duration (about 80% to 100% of evaluation time) in the sodium-reduced than regular ham (within 90% to 100% evaluation time), and perception of *ham* and *umami* were increased in the regular ham.

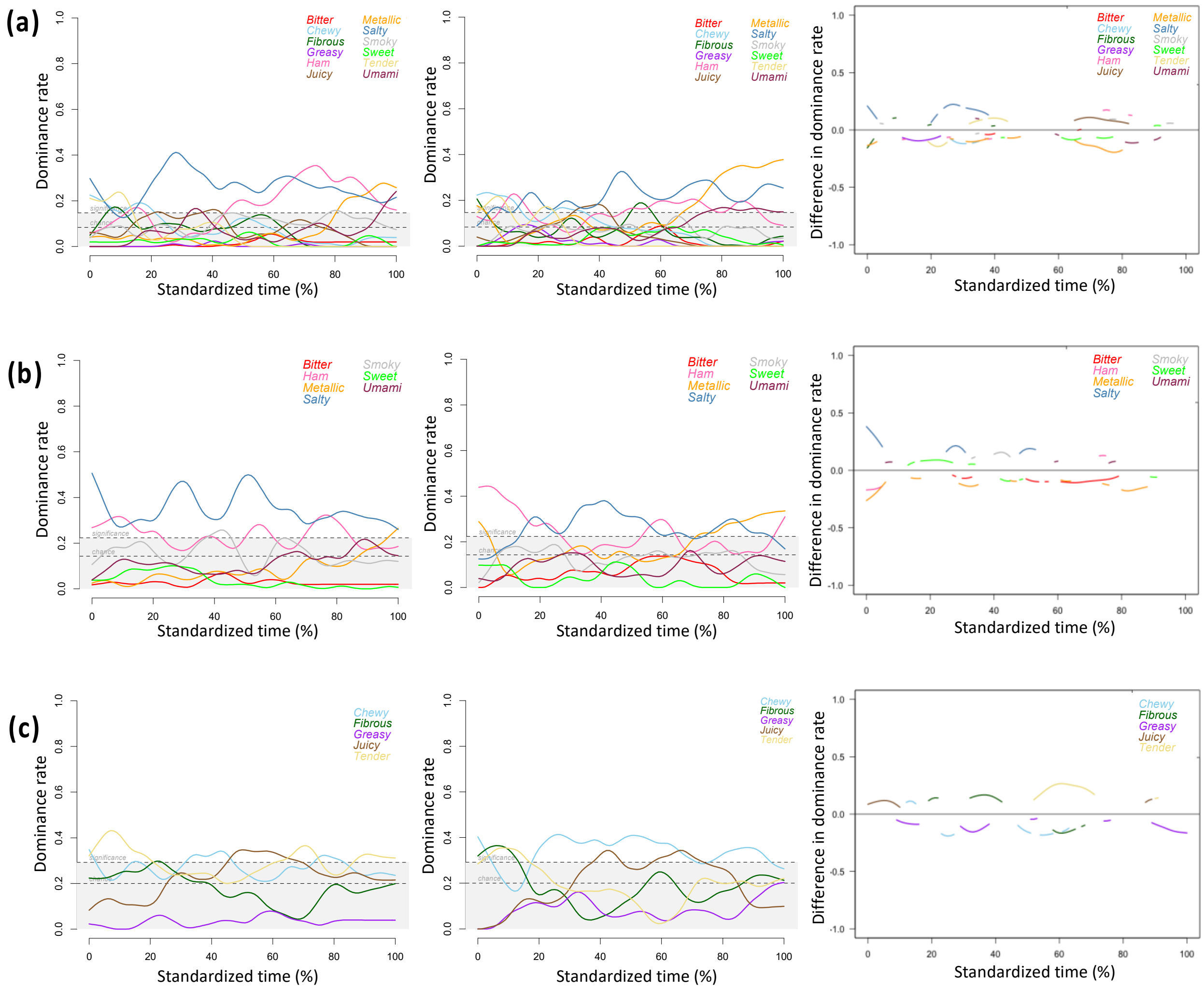


Figure 3.3. TDS profiles for regular (left) and sodium-reduced (middle) ham, and significant difference curves (right) obtained by 3 methods using different attribute modalities: across modalities (a), flavor modality (b) and texture modality (c) (n=51).

There were many significant attribute differences between regular and sodium-reduced hams in TDS evaluations while *bitter* was the single significantly different attribute revealed in TCATA evaluations. *Bitter* had greater dominance rates near 40% of evaluation time and greater citation proportions within 55% to 80% of evaluation time in the sodium-reduced than regular ham. With a greater dominance rate and a greater citation proportion, *metallic* might be more noticeable in sodium-reduced than regular ham within 80% to 100% of evaluation time. However, this was not observed in TDS and TCATA significant difference curves although TDS detected significant metallic differences at several timepoints prior to 80% of evaluation time.

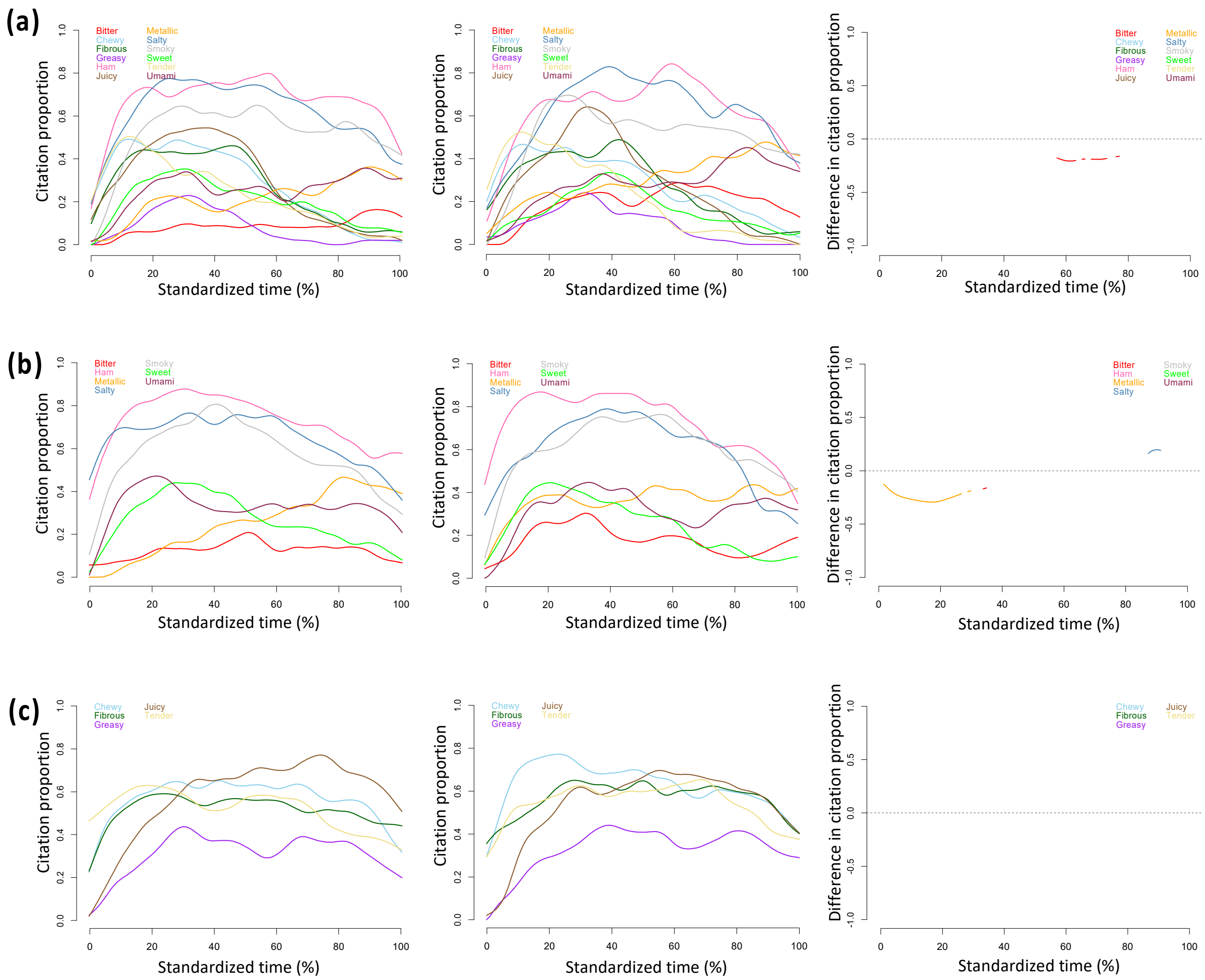


Figure 3.4. TCATA temporal profiles for regular (left) and sodium-reduced (middle) ham, and significant difference curves (right) obtained by 3 methods using different attribute modalities: across modalities (a), flavor modality (b) and texture modality (c) (n=51).

3.3.1.4. Cream of mushroom soup

TDS and TCATA provided comparable information for the key sensory attributes used to characterize and differentiate the regular and sodium-reduced soups, including *creamy, thick, salty, cream flavor, mushroom, starchy* and *umami*. In both TDS and TCATA evaluations of the first sip of soup (Figure 3.5a, b), the regular soup was characterized by *salty* while the sodium-reduced soup was characterized by *thick* and *creamy* in early evaluation. In mid evaluation, the regular soup was characterized by *mushroom* (at about 30% of standardized time for TDS and during mid evaluation for TCATA), *salty* and *cream flavor* while the sodium-reduced soup was characterized by *starchy, mushroom* and *cream flavor*. There were many significant attribute differences in temporal perception between the regular and sodium-reduced soups, identified in both TDS and TCATA evaluations (Figure 3.5c). *Salty* was more noticeable/cited in the regular than sodium-reduced soup throughout the evaluation. Compared to regular soup, sodium-reduced soup was more noticeable/cited for *thick*, *creamy*, *sweet* and *starchy* at various timepoints, in longer time periods for TCATA than TDS profiles.

There were a greater number of noticed attributes in TDS than TCATA profiles. For regular soup, *cream flavor* reached to a comparable citation proportion with that of *salty* near the mid evaluation of TCATA while *cream flavor* was more noticeable than *salty* at the same timepoint in TDS. *Mushroom* was the most cited attribute of both regular and sodium-reduced soups in late TCATA evaluation, but it did not reach the significant dominance between 70% and 95% of evaluation time in the sodium-reduced soup. Additionally, *umami* was the most dominant attribute in the regular soup within 80% - 100% of evaluation time while *umami* sequentially shared the highest dominance rate with *cream flavor* and *starchy* in the sodium-reduced soup at the same time period.

3.3.2. Multiple intake evaluation of chips and soup

Differences in the temporal profile of regular and sodium reduced products were identified over multiple intakes. TDS and TCATA product trajectories for multi-intake evaluations of chips and soup (Figure 3.6) shared similarities to temporal profiles generated from evaluations of the first intake (as described in section 3.3.1.1 and section 3.3.1.4).

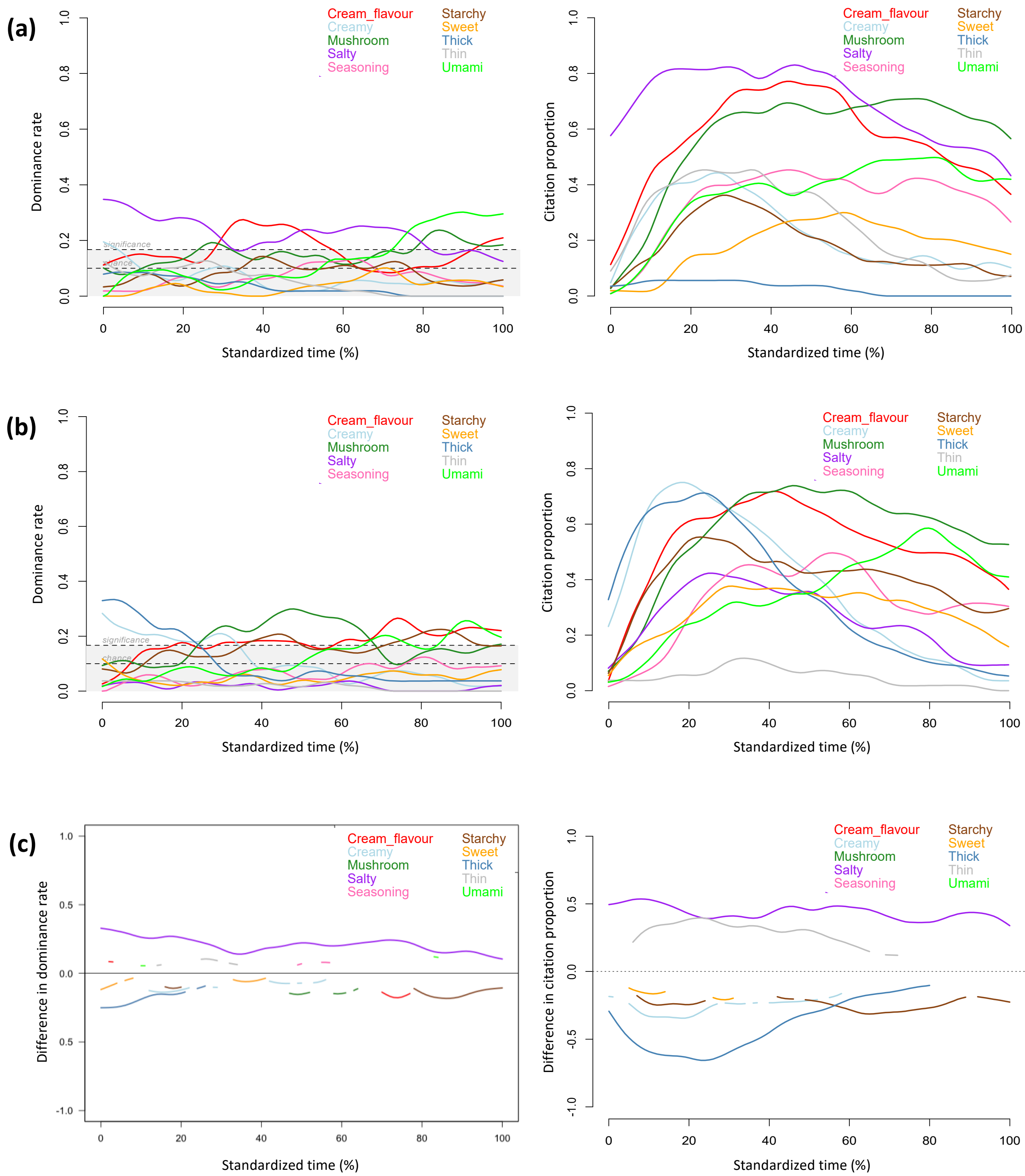


Figure 3.5. Temporal profiles for regular (a) and sodium-reduced (b) soup, and significant difference curves (c) obtained by TDS (left) and TCATA (right) evaluations of the first intake (n=54).

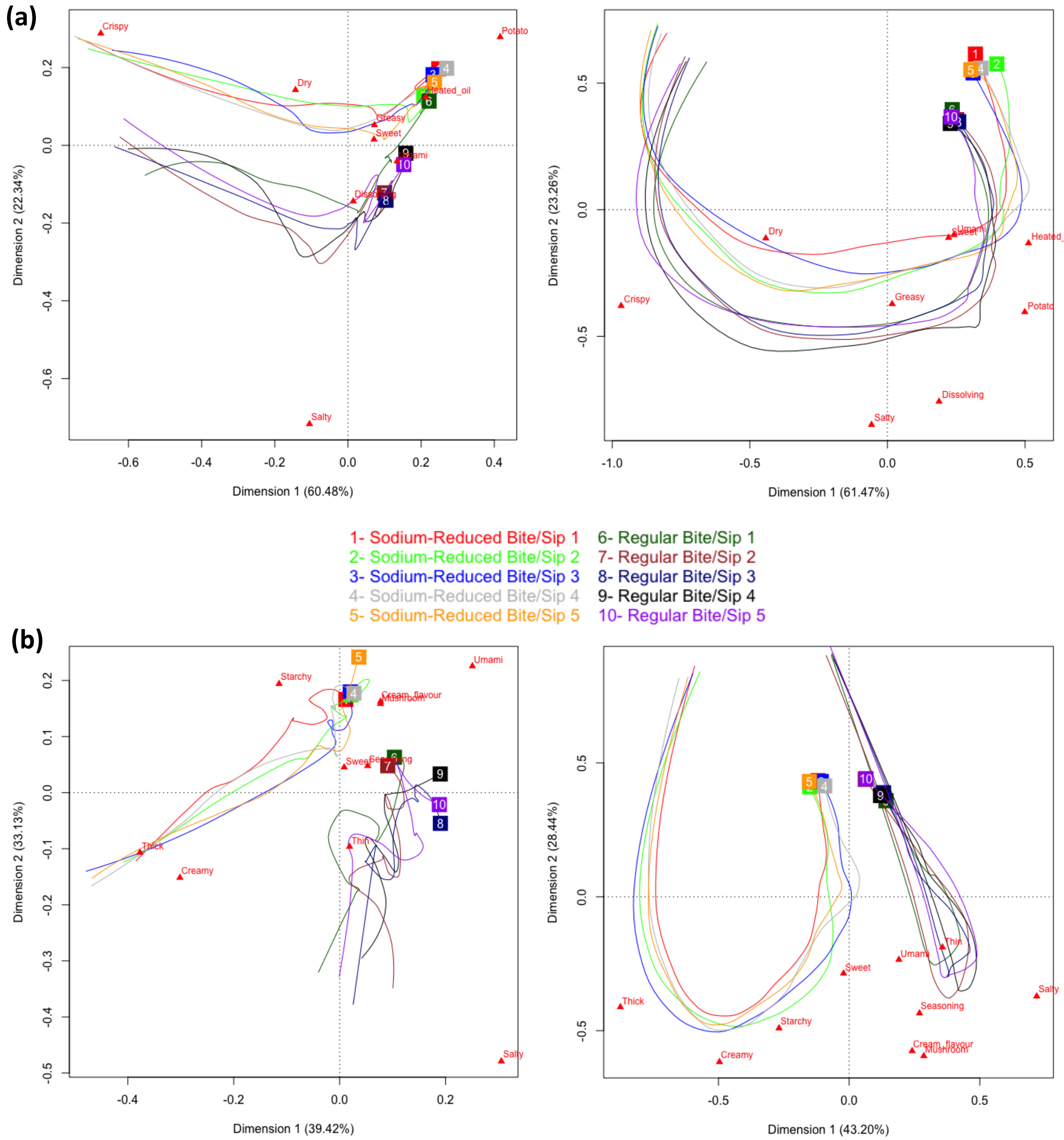


Figure 3.6. Product trajectories for Principal Component Analysis on time-standardized TDS (left) and TCATA (right) data for multi-intake evaluations of regular and sodium-reduced chips (a) and soup (b); labeled at the respective trajectory endpoints.

Only distinct differences in temporal profiles between regular and sodium-reduced products were retained throughout 5 intakes; a less detailed description was generated compared to TDS/TCATA curves of the first intake (Appendix 2). Product trajectories for regular and sodium-reduced chips have the same direction according to the first dimension of the PCA for both TDS and TCATA, which differentiated product characteristics at different evaluation periods; both regular and sodium-reduced chips were characterized by *crispy* in early TDS and TCATA evaluation, *potato* in late TDS and TCATA evaluation and *heated oil* in late TCATA evaluation (Figure 3.6a). The second dimension of the PCA for both TDS and TCATA evaluations of chips was correlated with *salty*, the attribute which most differentiated regular and sodium-reduced chips. Sodium-reduced chips were less noticed in *salty* throughout evaluations. *Dissolving* was correlated with the second dimension of the PCA for TCATA evaluation, characterizing the regular and sodium-reduced chips in mid evaluation. Moreover, *crispy* and *potato* were also correlated with the second dimension of the PCA map for TDS evaluation, differentiating regular and sodium-reduced chips for their dominance rates; the sodium-reduced chips had a higher dominance rate for *crispy* and *potato* than the regular chips in TDS profiles.

The difference between regular and sodium-reduced products was larger for soup than for chips, which is observed through different directions between regular and sodium-reduced soup trajectories on the PCA for TDS and TCATA. The sodium-reduced soup was characterized by *thick* and *creamy* in early TDS and TCATA evaluation. The direction of trajectories displaying changes in product characteristics over evaluation time was correlated to the second dimension. Both dimensions were correlated to *salty*, which discriminated different evaluation periods as well as regular and sodium-reduced soups. The regular soup was characterized by *salty* for most evaluation time in both TDS and TCATA profiles, but not for the sodium-reduced soup. Both dimensions in the PCA plot for TDS evaluations of soup were correlated to *umami*, indicating that soups were characterized by *umami* by more judgements in late evaluation than early evaluation and in the regular than sodium-reduced soup. *Starchy* characterized the sodium-reduced soup; it was dominant in the sodium-reduced but not the regular soup and had a greater citation proportion in the sodium-reduced than regular soup. *Cream flavor* and *mushroom* were highly cited evaluation of both regular and sodium-reduced soup.

The number of attributes reaching significant dominance rates in TDS or highly cited in TCATA did not change over multiple intakes for both regular and sodium-reduced samples (Appendix 2). The timepoint and duration of dominance for attributes changed slightly from intake to intake in TDS but were more consistent in TCATA. This result is observed through a larger variation among TDS than TCATA trajectories of different intakes for both chips and soup. Within each product, the TCATA profile was consistent across 5 intakes; there were 2 distinct groups of product trajectories with similar patterns for the regular and sodium-reduced products (Figure 3.6, right). Patterns of TDS trajectories differed across intakes, with larger variation in the regular than sodium-reduced products (Figure 3.6, left), i.e. in late TDS evaluations of regular chips, the first bite was more noticeable in *heated oil*, the second and third bites were more noticeable in *salty* compared to the fourth and fifth bites.

3.3.3. Temporal evaluation by modality

The results of TCATA by modality agreed with TCATA across modalities, but not TDS evaluations. Attribute curves for TCATA across modalities and TCATA by modality were similar in their pattern although the order of their citation proportions was different (Figure 3.4). *Ham, salty* and *smoky* were the most cited. The citation proportion of *smoky, sweet, umami* and all texture attributes were lower in the evaluation across modality than by modality. The citation proportion of *metallic* in early to mid evaluation was greater in the sodium-reduced than regular ham by modality but not across modalities. The number of flavor attributes reaching significant dominance rates was smaller in TDS by modality than in TDS across modalities; *umami* was noticed at the end of ham evaluation, with a greater dominance rate and a longer duration in the sodium-reduced than the regular ham, but it did not reach the significance rate in TDS by flavor modality (Figure 3.3).

For evaluation across modalities, the regular and sodium-reduced ham were characterized by texture attributes in short durations in early evaluation for both TDS (*chewy*, *tender*, *fibrous*) and TCATA (*chewy*, *tender* at the beginning of evaluation) and by flavor attributes during most of the evaluation time. Four of the five texture attributes (*chewy*, *tender*, *fibrous, juicy*) were selected by participants to describe regular and sodium-reduced hams for both temporal methods, with or without evaluation by modality. Although *greasy* was perceived in both regular and sodium-reduced hams, its insignificant dominance rates in TDS curves (Figure 3.3c) and similar patterns in TCATA curves (Figure 3.4c) suggest that participants did not perceive differences in the temporal perception of *greasy* between the regular and sodium-reduced hams.

Significant differences in temporal profiles between regular and sodium-reduced hams differed between methods. Although there were a few attributes not reaching significant dominance rates (i.e. *sweet* and *bitter*), TDS evaluations provided significant differences in dominance rates between regular and sodium reduced hams for all evaluated attributes regardless of modality. By contrast, TCATA by modality detected a greater number of significantly different flavor attributes between the hams than TCATA across modalities; *metallic* during 30% of evaluation time at the beginning, followed by *bitter* for a few seconds and *salty* in a short period near the end for TCATA by modality, and *bitter* between 55% and 80% of the standardized time for TCATA across modalities. No significant differences in texture attributes were observed in TCATA by modality although *chewy* was cited by more judgements for the sodium-reduced ham than the regular ham at 20-30% of evaluation time.

3.4. Discussion

Changes in temporal sensory profiles between sodium-reduced and conventional counterparts differed across products and between temporal methods. Compared to regular products, sodium-reduced products were characterized as *salty* by fewer judgements throughout evaluation of chips and soup regardless of temporal methods and intakes, and during evaluation of ham except for TCATA across modalities, but not for the evaluation of canned corn.

Uni-point evaluation of a sensory attribute may not differ between a regular and sodium-reduced product, but its temporal perception may be changed. In the previous study of uni-point sensory evaluation of regular and sodium-reduced potato chips (Chapter 2), sodium-reduced chips were perceived as *less salty*, *less oily* and *less flavourful* by 100 consumers using Rate-All-That-Apply (RATA). Although uni-point ratings for *potato* and *dry* were not significantly different, temporal curves for these two attributes in the current study were different between regular and sodium-reduced chips. The smaller salt particles used to reduce sodium in plain and seasoned Lay's potato chips (Wall, 2010), shoestring potatoes (Freire et al., 2015; Rodrigues et al., 2016) and potato crisps (Rama et al., 2013), produced the same salty intensity but in a shorter time (Quilaqueo, Duizer, & Aguilera, 2015). If this technique is used for the current sodium-reduced current Lay's potato chips, the 50% sodium reduction lead to changes in the traditional temporal sensory profile, with a decrease of saltiness and dominance of other flavor attributes. The use of the salt replacer potassium chloride in the current sodium-reduced ham (Table 3.1) enhanced the temporal perception of *metallic* and *bitter* tastes, confirming that potassium chloride induces *metallic* and *bitter* off-taste in processed meats as reported in previous studies (Gaudette & Pietrasik, 2017; Greiff et al., 2015; Inguglia et al., 2017). However, differences in *metallic* and *bitter* between the current hams were not observed through the RATA consumer panel in the previous study (Chapter 2).

Salt did not only elicit saltiness but also enhance other flavors, which was observed through the increased perception of *ham* and *umami* in TDS evaluation of the regular ham, and *umami* in TDS evaluation of soup compared to the sodium-reduced products. The taste-taste interaction between *sweet* and *salty* tastes was observed in the evaluation of canned corn. Sodium-reduced corn was characterized by *salty* by more judgements than the regular corn in both TDS and TCATA. Moreover, *sweet* was more noticeable in TDS evaluations of the regular corn than sodium-reduced corn. It has been suggested that sweetness suppresses salty taste at moderate concentrations, and that sodium enhances sweetness at low concentrations and has variable effects through the moderate concentration range (Keast & Breslin, 2003). Therefore, the larger concentration of salt in the regular corn may have contributed to the increased sweet taste and less noticeable salty taste compared to the sodium-reduced corn. For food products in which sweetness is a desirable attribute, a decrease in sweet perception or an increase in salty taste due to sodium reduction would contribute to consumer preference changes through a change in the expected product temporal profiles.

The large differences in composition and texture of the current soup samples lead to perceptible changes in all evaluated attributes between methods and across intakes. It is reported that soup prepared in oil-in-water emulsions with greater viscosity was perceived as saltier (Busch et al., 2013; Cornelia, Triyanti, Prasetia, & Purnomo, 2016; Lima et al., 2018). Perhaps this technique was applied to the reformulation for sodium reduction of the current cream of mushroom soup, where the sodium-reduced soup was noticed more in *creamy* and *thick* attributes than the regular soup in early evaluation.

TDS provided a more detailed description of temporal attribute changes and differentiation of the temporal sensory profiles between regular and sodium-reduced products. Although consumers had a greater consensus in selecting perceived attributes in TCATA than selecting the dominant attributes in TDS (greater percentages of choices), TDS detected a greater number of significant differences in temporal profiles between regular and sodium-reduced products. Aligned with observations of previous studies (Ares et al., 2015; Nguyen et al., 2018), TCATA provided a more detailed description of sensory attributes at a given time. Attributes were concurrently perceived in TCATA evaluations of regular and sodium-reduced product pairs, while the dominant attributes differed between regular and sodium-reduced product pairs at a given moment. Moreover, among perceived attributes, the dominant attribute changed over time, hence, the number of the most dominant/cited attributes over evaluation time was greater in TDS than TCATA profiles.

By contrast, TCATA was reported to provide a more (Ares et al., 2017, 2015; Nguyen et al., 2018; Parker et al., 2018) or comparable (Esmerino et al., 2017) informative description and discrimination compared to TDS. Some previous studies involved trained panelists (Ares et al., 2015; Nguyen et al., 2018; Parker et al., 2018) and others involved consumers (Ares et al., 2015; Esmerino et al., 2017), in which commercial samples of different brands or experimental research samples with tailored ingredient levels were differentiated by both TDS and TCATA. Differences among those samples would be larger than differences between the commercial regular and sodium-reduced formulations of the same brand used in this study, differences which are minimized to be acceptable to consumers. The opposing observations may also be the result of panel performance, differences in product categories, the size of the differences between samples, and study objectives. This study explored the possibility of using a small consumer panel for discrimination of regular and sodium-reduced foods. A familiarization step was used to generate the attribute list and instruct participants how to perform the test. The data from triplicate evaluations showed significant differences between the regular and sodium-reduced products for all evaluated food items.

Temporal profiles were not evaluated in association with participants' hedonic perception; therefore, we were unable to determine whether the additional significant differences between the regular and sodium-reduced products identified by TDS relative to TCATA contribute to consumer preference. The dominant attributes, which catch consumers' attention, may be more important to consumer preference and choice of sodium-reduced foods. Further studies comparing TDS and TCATA in association with consumer hedonic perception would be useful to confirm the present findings and identify drivers of liking, and aid selection of the appropriate temporal method for use in sodium-reduced product development. Moreover, the comparisons between TDS and TCATA and selection of dominant attributes may be different among consumer segments. Segmentation of consumers by consumers' attributes, i.e. consumption habits and preference of sodium-reduced foods, could provide insights about their temporal perception of sodium-reduced formulations for a targeted consumer segment.

Although there were several studies using multi-intake evaluation in TI or TDS to assess temporal profiles of food products (i.e. Galmarini, Loiseau, Debreyer, Visalli, & Schlich, 2017; Gotow et al., 2018; Zorn et al., 2014), this is the first study using multi-intake evaluation in TCATA compared with TDS for sodium-reduced foods. It is reported that multiple intakes might have an influence on sensory perception (de Wijk, Engelen, Prinz, & Weenen, 2003), and changes in TDS profiles were identified from intake to intake for orange juice with different sweeteners (Zorn et al., 2014). In this study, multiple intakes had an influence on TDS profiles but not TCATA profiles; multiple intakes did not change the number of significantly dominant attributes, but slightly changed the duration of dominance in TDS profiles. This finding aligns with the study of Galmarini et al. (2017); the number of different attributes cited did not change from bite to bite in any cheese, and the bite effect on the duration of dominance was observed for some cheese samples. The lack of intake effect might come from the fact that TDS and TCATA do not evaluate attribute intensity. This finding was also observed in the study of Antunez et al. (Antúnez et al., 2017) on bread using a descriptive method, CATA.

Perceived sensations of a product are complex due to the interaction among its different components. Multi-intake evaluation can help identify the effect of adaptation and build-up of attribute intensity through repeated exposure of the product (Jamieson & Watling, 2017). For example, *heated oil* was noticed in the first intake of regular chips, but it was less noticeable from the second intake to the fifth intake because it may have been masked by the intense salty taste built up from intake to intake. Additionally, the sensory differences between regular and sodium-reduced chips were decreasing from intake to intake in TDS evaluation (Appendix 2). The current results of the multi-intake evaluations suggest a thorough consideration of the appropriate method for description of regular and sodium-reduced products; single-intake evaluation could be representative of TCATA profiles over repeated consumption, but not for TDS profiles. For TDS profiles, the use of multi-intake evaluation will be helpful to observe differences between regular and sodium-reduced products across intakes.

Ham profiles were different when performed across modalities and by modality; evaluation by modality provided less detailed description of TDS profiles and identified more product pair differences in TCATA profiles. There are limited studies on sensory evaluation by modality of food products. Although temporal evaluation by modality is suggested for TDS (Monaco, Chengcheng, Masi, & Cavella, 2014; Nguyen et al., 2018; Varela et al., 2018), evaluation across modalities provided more detailed description of TDS profiles and comparable description of TCATA profiles, and it might provide a representative description of the sensory experiences during usual consumption of food products. Moreover, restricting the evaluation to a single modality may limit the ecological validity of a study. Aligned with the study of Nguyen, Næs, & Varela (2018) on TDS by modality for semi-solid foods, TDS across modalities and TDS by modality provided some differences in dominant attributes throughout evaluation time, and temporal evaluation by modality discriminated the regular and sodium-reduced ham better, especially for TCATA. Nguyen, Næs, & Varela (2018) indicated that TDS by modality provided a greater number of different attributes reaching significant rates than TDS across modalities, while an opposing result was observed in this study. The different numbers of attributes in each of flavor (7) and texture (5) modalities, and the forced choice of the dominant attribute through the two channels, chemoreceptors and mechanoreceptors for the perception of flavor and texture respectively, may have lead to less flavor perception being considered and selected in TDS across modalities. In TDS by modality, all flavor attributes were considered, and concurrent dominant attributes might lead to lower participant consensus. Consequently, a greater number of flavor attributes did not reach significant dominance rates in TDS by modality than in TDS across modalities.

Several findings were generated from the multi-intake evaluation for two different product categories, chips as a solid food and soup as a liquid food. It is necessary to study multi-intake evaluation for other products of different complexity or products whose attribute intensities are built up from intake to intake (i.e. sodium-reduced spices) in order to confirm the current findings. Moreover, results of the temporal evaluation by modality were different from the results of the evaluation across modalities, but the evaluation by modality was performed only for ham. Further studies on products of different physical states, solid, semi-solid and liquid, are needed to generate stronger comparisons of TDS and TCATA and to support selection of the most appropriate temporal method for each food type. The comparisons could be performed concurrently through the combination of multi-intake evaluation and evaluation by modality. Additionally, the desired outcomes, i.e. detailed description of temporal sensory profiles or discrimination of temporal sensory profiles between regular and sodium-reduced formulations, would be important for the method selection.

3.5. Conclusions

We observed that sodium reduction in food products resulted in differences in their temporal profiles relative to their regular counterparts in not only salty taste but also other attributes, noticeably *dry* for chips, *sweet* for corn, *chewy*, *bitter* and *metallic* for ham, *thick*, *creamy*, *sweet* and *starchy* for soup. Sodium-reduced chips, ham and soup, but not corn, were characterized by *salty* less than their regular counterparts. Temporal sensory attribute profiles of regular and sodium-reduced foods differed between methods. TDS detected a greater number of sensory attributes to discriminate between regular and sodium-reduced products than TCATA. Compared to TDS, TCATA generated more consistent profiles across methods, single and multi-intake evaluation, and evaluation across modalities and by modality. Temporal profiles of the regular and sodium reduced products were significantly different over multi-intake sampling for chips and soup; the difference was larger for soup than for chips. The evaluation by modality provided a less detailed description of TDS profiles and identified more differences in TCATA profiles between the regular and sodium-reduced ham than the evaluation across modalities. The comparisons across products and methods provide a guide to the selection of the most appropriate temporal method for studies of sodium-reduced foods. The current findings and the application of current methods to other food products may support the development of sodium-reduced formulations acceptable to consumers.

3.6. References

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2017). Consumer perception of salt-reduced breads: Comparison of single and two-bites evaluation. *Food Research International*, *100*(July), 254–259. https://doi.org/10.1016/j.foodres.2017.07.014

Antúnez, L., Giménez, A., Vidal, L., & Ares, G. (2018). Partial replacement of NaCl with KCl in bread: Effect on sensory characteristics and consumer perception. *Journal of Sensory Studies*, *33*(5), 1–12. https://doi.org/10.1111/joss.12441

Arcand, J., Jefferson, K., Schermel, A., Shah, F., Trang, S., Kutlesa, D., … Abbe, M. R. L. (2016). Examination of food industry progress in reducing the sodium content of packaged foods in Canada : 2010 to 2013. *Appl. Physiol. Nutr. Metab.*, *41*(April), 1–7. https://doi.org/dx.doi.org/10.1139/apnm-2015-0617

Ares, G., Alcaire, F., Antúnez, L., Vidal, L., Giménez, A., & Castura, J. C. (2017). Identification of drivers of (dis)liking based on dynamic sensory profiles: Comparison of Temporal Dominance of Sensations and Temporal Check-all-that-apply. *Food Research International*, *92*, 79–87. https://doi.org/10.1016/j.foodres.2016.12.016

Ares, G., Castura, J. C., Antúnez, L., Vidal, L., Giménez, A., Coste, B., … Jaeger, S. R. (2016). Comparison of two TCATA variants for dynamic sensory characterization of food products. *Food Quality and Preference*, *54*, 160–172. https://doi.org/10.1016/j.foodqual.2016.07.006

Ares, G., Jaeger, S. R., Antúnez, L., Vidal, L., Giménez, A., Coste, B., … Castura, J. C. (2015). Comparison of TCATA and TDS for dynamic sensory characterization of food products. *Food Research International*, *78*, 148–158. https://doi.org/10.1016/j.foodres.2015.10.023

Busch, J. L. H. C., Yong, F. Y. S., & Goh, S. M. (2013). Sodium reduction: Optimizing product composition and structure towards increasing saltiness perception. *Trends in Food Science and Technology*, *29*(1), 21–34. https://doi.org/10.1016/j.tifs.2012.08.005

Cadena, R. S., Vidal, L., Ares, G., & Varela, P. (2014). Dynamic sensory descriptive methodologies. Time-intensity and temporal dominance of sensations. In P. Varela & G. Ares (Eds.), *Novel Techniques in Sensory Characterization and Consumer Profiling* (pp. 333–364). Boca Raton: CRC Press.

Castura, J. C. (2017). tempR: Temporal sensory data analysis. R package version 0.9.9.10. Retrieved from http://www.cran.r-project.org/package=tempR/

Castura, J. C. (2018). Dynamics of consumer perception. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 1: New approaches to classic methods* (Vol. 1, pp. 211–240). Elsevier Ltd. https://doi.org/https://doi.org/10.1016/B978-0-08-102089-0.00009-1

Castura, J. C., Antúnez, L., Giménez, A., & Ares, G. (2016). Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Quality and Preference*, *47*, 79–90. https://doi.org/10.1016/j.foodqual.2015.06.017

Chen, J. (2014). Food oral processing : Some important underpinning principles of eating and sensory perception. *Food Structure*, *1*(2), 91–105. https://doi.org/10.1016/j.foostr.2014.03.001

Cornelia, M., Triyanti, I., Prasetia, T., & Purnomo, C. (2016). Sensory evaluation and characterizations of emulsion containing sodium chloride and its application in corn soup. *Jurnal Teknologi Dan Industri Pangan*, *27*(2), 157–164. https://doi.org/10.6066/jtip.2016.27.2.157

da Silva, T. L. T., de Souza, V. R., Pinheiro, A. C. M., Nunes, C. A., & Freire, T. V. M. (2014). Equivalence salting and temporal dominance of sensations analysis for different sodium chloride substitutes in cream cheese. *International Journal of Dairy Technology*, *67*(1), 31–38. https://doi.org/10.1111/1471-0307.12100

de Souza, V. R., Freire, T. V. M., Saraiva, C. G., de Deus Souza Carneiro, J., Pinheiro, A. C. M., & Nunes, C. A. (2013). Salt equivalence and temporal dominance of sensations of different sodium chloride substitutes in butter. *Journal of Dairy Research*, *80*(3), 319–325. https://doi.org/10.1017/S0022029913000204

de Wijk, R. A., Engelen, L., Prinz, J. F., & Weenen, H. (2003). The influence of bite size and multiple bites on oral texture sensations. *Journal of Sensory Studies*, *18*(5), 423–435. https://doi.org/10.1111/j.1745-459X.2003.tb00398.x

Esmerino, E. A., Castura, J. C., Ferraz, J. P., Tavares Filho, E. R., Silva, R., Cruz, A. G., … Bolini, H. M. A. (2017). Dynamic profiling of different ready-to-drink fermented dairy products: A comparative study using Temporal Check-All-That-Apply (TCATA), Temporal Dominance of Sensations (TDS) and Progressive Profile (PP). *Food Research International*, *101*(June), 249–258. https://doi.org/10.1016/j.foodres.2017.09.012

Freire, T. V. M., Freire, D. O., de Souza, V. R., Gonçalves, C. S., Carneiro, J. de D. S., Nunes, C. A. A., … Marques Pinheiro, A. C. (2015). Salting potency and Time-Intensity profile of microparticulated sodium chloride in shoestring potatoes. *Journal of Sensory Studies*, *30*(1), 1–9. https://doi.org/10.1111/joss.12129

Galmarini, M. V., Loiseau, A.-L. L., Debreyer, D. D. D., Visalli, M., & Schlich, P. (2017). Use of multi-intake Temporal Dominance of Sensations (TDS) to evaluate the influence of wine on cheese perception. *Journal of Food Science*, *82*(11), 2669–2678. https://doi.org/10.1111/1750-3841.13932

Gaudette, N. J., & Pietrasik, Z. (2017). The sensory impact of salt replacers and flavor enhancer in reduced sodium processed meats is matrix dependent. *Journal of Sensory Studies*, *32*(1), 1–11. https://doi.org/10.1111/joss.12247

Gonçalves, C., Rodrigues, J. J. J., Júnior, H., Carneiro, J. J., Freire, T., Freire, L. L. L., … Freire, L. L. L. (2017). Sodium reduction in margarine using NaCl substitutes. *Anais Da Academia Brasileira De Ciencias*, *89*(3), 2505–2513. https://doi.org/10.1590/0001-3765201720150618

Gotow, N., Omata, T., Uchida, M., Matsuzaki, N., Takata, S., Hagiwara, I., & Kobayakawa, T. (2018). Multi-sip Time-Intensity evaluation of retronasal aroma after swallowing Oolong tea beverage. *Foods*, *7*(11). https://doi.org/10.3390/foods7110177

Greiff, K., Mathiassen, J. R., Misimi, E., Hersleth, M., Aursand, I. G., Ekrem, M., … Aursand, I. G. (2015). Gradual reduction in sodium content in cooked ham, with corresponding change in sensorial properties measured by sensory evaluation and a multimodal Machine vision system. *PLoS ONE*, *10*(9), 1–15. https://doi.org/10.1371/journal.pone.0137805

Hayes, J. E., & Keast, R. S. J. (2011). Two decades of supertasting: Where do we stand? *Physiology and Behavior*, *104*(5), 1072–1074. https://doi.org/10.1016/j.physbeh.2011.08.003

Health Canada. (2018). *Sodium reduction in processed foods in Canada: An evaluation of progress toward voluntary targets from 2012 to 2016*. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/legislation-guidelines/guidance-documents/guidance-food-industry-reducing-sodium-processed-foods-progress-report-2017.html

Inguglia, E. S., Zhang, Z., Tiwari, B. K., Kerry, J. P., & Burgess, C. M. (2017). Salt reduction strategies in processed meat products – A review. *Trends in Food Science & Technology*, *59*, 70–78. https://doi.org/10.1016/j.tifs.2016.10.016

Israr, T., Rakha, A., Sohail, M., Rashid, S., & Shehzad, A. (2016). Salt reduction in baked products: Strategies and constraints. *Trends in Food Science and Technology*, *51*, 98–105. https://doi.org/10.1016/j.tifs.2016.03.002

Jaeger, S. R., Alcaire, F., Hunter, D. C., Jin, D., Castura, J. C., & Ares, G. (2018). Number of terms to use in temporal check-all-that-apply studies (TCATA and TCATA Fading) for sensory product characterization by consumers. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2017.09.013

Jamieson, L., & Watling, E. (2017). Multiple-ingestion Time-Intensity. In *Time-dependent measures of perception in sensory evaluation* (pp. 321–342). Retrieved from %3CGo

Keast, R. S. J., & Breslin, P. A. S. (2003). An overview of binary taste-taste interactions. *Food Quality and Preference*, *14*(2), 111–124. https://doi.org/10.1016/S0950-3293(02)00110-6

Kloss, L., Meyer, J. D., Graeve, L., & Vetter, W. (2015). Sodium intake and its reduction by food reformulation in the European Union - A review. *NFS Journal*, *1*, 9–19. https://doi.org/10.1016/j.nfs.2015.03.001

Lawless, H. T., & Heymann, H. (2010). Physiological and psychological foundations of sensory function. In H. T. Lawless & H. Heymann (Eds.), *Sensory evaluation of food: principles and practices* (2nd ed., pp. 19–56). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4615-7843-7_2

Lenfant, F., Loret, C., Pineau, N., Hartmann, C., & Martin, N. (2009). Perception of oral food breakdown. The concept of sensory trajectory. *Appetite*, *52*(3), 659–667. https://doi.org/10.1016/j.appet.2009.03.003

Liem, D. G., Miremadi, F., & Keast, R. S. J. (2011). Reducing sodium in foods: The effect on flavor. *Nutrients*. https://doi.org/10.3390/nu3060694

Lima, A., Dufauret, M., le Révérend, B., Wooster, T. J., le Reverend, B., & Wooster, T. J. (2018). Deconstructing how the various components of emulsion creamers impact salt perception. *Food Hydrocolloids*, *79*, 310–318. https://doi.org/10.1016/j.foodhyd.2018.01.005

Lorido, L., Estévez, M., & Ventanas, S. (2018). Fast and dynamic descriptive techniques (Flash Profile, Time-intensity and Temporal Dominance of Sensations) for sensory characterization of dry-cured loins. *Meat Science*, *145*, 154–162. https://doi.org/10.1016/j.meatsci.2018.06.028

Lorido, L., Hort, J., Estevez, M., & Ventanas, S. (2016). Reporting the sensory properties of dry-cured ham using a new language: Time intensity (TI) and temporal dominance of sensations (TDS). *Meat Science, 121*, 166–174. https://doi.org/10.1016/j.meatsci.2016.06.009

Monaco, R. di, Chengcheng, S., Masi, P., & Cavella, S. (2014). Temporal dominance of sensations: a review. *Trends in Food Science & Technology*, *38*(2), 104–112.

Monteiro, C. A., Cannon, G., Moubarac, J. C., Levy, R. B., Louzada, M. L. C., & Jaime, P. C. (2017). The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. *Public Health Nutrition*, *21*(01), 5–17. https://doi.org/10.1017/S1368980017000234

Nguyen, Q. C., Næs, T., & Varela, P. (2018). When the choice of the temporal method does make a difference: TCATA, TDS and TDS by modality for characterizing semi-solid foods. *Food Quality and Preference*, *66*(December 2017), 95–106. https://doi.org/10.1016/j.foodqual.2018.01.002

Parker, M. N., Lopetcharat, K., & Drake, M. A. (2018). Consumer acceptance of natural sweeteners in protein beverages. *Journal of Dairy Science*, *101*(10), 8875–8889. https://doi.org/10.3168/jds.2018-14707

Paulsen, M. T., Nys, A., Kvarberg, R., & Hersleth, M. (2014). Effects of NaCl substitution on the sensory properties of sausages: Temporal aspects. *Meat Science*, *98*(2), 164–170. https://doi.org/10.1016/j.meatsci.2014.05.020

Pineau, N., de Bouillé, A. G., Lepage, M., Lenfant, F., Schlich, P., Martin, N., & Rytz, A. (2012). Temporal Dominance of Sensations: What is a good attribute list? *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2012.04.004

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., … Köster, E. (2009). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455. https://doi.org/10.1016/j.foodqual.2009.04.005

Powles, J., Fahimi, S., Micha, R., Khatibzadeh, S., Shi, P., Ezzati, M., … Mozaffarian, D. (2013).

Global, regional and national sodium intakes in 1990 and 2010: a systematic analysis of 24 h urinary sodium excretion and dietary surveys worldwide. *BMJ Open*, *3*(12), e003733. https://doi.org/10.1136/bmjopen-2013-003733

Quilaqueo, M., Duizer, L., & Aguilera, J. M. (2015). The morphology of salt crystals affects the perception of saltiness. *Food Research International*, *76*, 675–681. https://doi.org/10.1016/j.foodres.2015.07.004

R Core Team. (2017). R: A language and environment for statistical computing. *R Foundation for Statistical Computing, Vienna, Austria*. Retrieved from https://www.r-project.org/

Rama, R., Chiu, N., Carvalho Da Silva, M., Hewson, L., Hort, J., & Fisk, I. D. (2013). Impact of salt crystal size on in-mouth delivery of sodium and saltiness perception from snack foods. *Journal of Texture Studies*, *44*(5), 338–345. https://doi.org/10.1111/jtxs.12017

Rodrigues, D. M., de Souza, V. R., Mendes, J. F., Nunes, C. A., & Pinheiro, A. C. M. (2016). Microparticulated salts mix: An alternative to reducing sodium in shoestring potatoes. *LWT - Food Science and Technology*, *69*, 390–399. https://doi.org/10.1016/j.lwt.2016.01.056

Rodrigues, J. F., Goncalves, C. S., Pereira, R. C., Carneiro, J. D. S., & Pinheiro, A. C. M. (2014). Utilization of temporal dominance of sensations and time intensity methodology for development of low-sodium Mozzarella cheese using a mixture of salts. *Journal of Dairy Science*, *97*(8), 4733–4744. https://doi.org/10.3168/jds.2014-7913

Rodrigues, J. F., Junqueira, G., Gonçalves, C. S., Carneiro, J. D. S., Pinheiro, A. C. M., & Nunes, C. A. (2014). Elaboration of garlic and salt spice with reduced sodium intake. *Anais Da Academia Brasileira de Ciencias*, *86*(4), 2065–2075. https://doi.org/10.1590/0001-3765201420130464

Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2016). Current status of salt reduction in bread and bakery products – A review. *Journal of Cereal Science*, *72*, 135–145. https://doi.org/10.1016/j.jcs.2016.10.010

Silva, H. L. A., Balthazar, C. F., Silva, R., Vieira, A. H., Costa, R. G. B., Esmerino, E. A., … Cruz, A. G. (2018). Sodium reduction and flavor enhancer addition in probiotic prato cheese: Contributions of quantitative descriptive analysis and temporal dominance of sensations for sensory profiling. *Journal of Dairy Science*, *101*(10), 8837–8846.

https://doi.org/10.3168/jds.2018-14819

Stieger, M., & Van de Velde, F. (2013). Microstructure, texture and oral processing: New ways to reduce sugar and salt in foods. *Current Opinion in Colloid and Interface Science*, *18*(4), 334–348. https://doi.org/10.1016/j.cocis.2013.04.007

Tuorila, H., & Monteleone, E. (2009). Sensory food science in the changing society: Opportunities, needs, and challenges. *Trends in Food Science and Technology*. https://doi.org/10.1016/j.tifs.2008.10.007

Varela, P., Antúnez, L., Carlehög, M., Alcaire, F., Castura, J. C., Berget, I., … Ares, G. (2018). What is dominance? An exploration of the concept in TDS tests with trained assessors and consumers. *Food Quality and Preference*, *64*. https://doi.org/10.1016/j.foodqual.2017.10.014

Ventanas, S., Puolanne, E., & Tuorila, H. (2010). Temporal changes of flavour and texture in cooked bologna type sausages as affected by fat and salt content. *Meat Science*, *85*(3), 410–419. https://doi.org/10.1016/j.meatsci.2010.02.009

Wall, B. (2010). PepsiCo develops "Designer Salt" to chip away at sodium intake - WSJ. *Wall Street Journal, Easten Edition*, 1–4. Retrieved from https://www.wsj.com/articles/SB10001424052748704534904575131602283791566

Wendin, K., Langton, M., Caous, L., & Hall, G. (2000). Dynamic analyses of sensory and microstructural properties of cream cheese. In *Food Chemistry* (Vol. 71, pp. 363–378). https://doi.org/10.1016/S0308-8146(00)00200-4

World Health Organization. (2016). *The SHAKE technical package for salt reduction*. Retrieved from http://www.who.int/dietphysicalactivity/publications/shake-salt-habit/en/

Zorn, S., Alcaire, F., Vidal, L., Giménez, A., & Ares, G. (2014). Application of multiple-sip temporal dominance of sensations to the evaluation of sweeteners. *Food Quality and Preference*, *36*, 135–143. https://doi.org/10.1016/j.foodqual.2014.04.003

Chapter 4. The influence of companion foods on sensory perception and liking of regular and sodium-reduced foods

4.1. Introduction

Interest in the development of sodium-reduced processed foods has increased in recent years as the majority of dietary sodium in many industrialized countries comes from processed foods (World Health Organization, 2016), and excessive dietary sodium intake is associated with health problems (Cappuccio et al., 2019; World Health Organization, 2016). Although a range of strategies have been applied to the development of sodium-reduced foods, success is limited as sodium reduction changes several product sensory attributes and consumer preference (Inguglia et al., 2017; Israr et al., 2016; Jaenke et al., 2017).

Many companion foods or foods and beverages are consumed together, such as bread with cheese, crackers with spreads, corn chips with salsa or French fries with ketchup for food pairs, cheese with wine and pizza with soft drinks for food – beverage pairs. There is limited sensory research of food pairing, in which foods or a food and a beverage are consumed together. Most studies of food – beverage pairs have focused on wine as the beverage of the pair, i.e. cheese and wine (Galmarini, Dufau, Loiseau, Visalli, & Schlich, 2018; Lahne, 2018). Food – food pairs (food pairs) may be consumed sequentially, i.e. burger and fries, or simultaneously, i.e. fries with ketchup. Among studies on sensory perception and liking of food pairs in the literature, there are no reports of sodium-reduced foods (Cherdchu & Chambers, 2014; Kremer et al., 2013; Meinert, Frøst, Bejerholm, & Aaslyng, 2011; Paulsen, Ueland, Nilsen, Öström, & Hersleth, 2012; Traynor, Burke, O'Sullivan, Hannon, & Barry-Ryan, 2013; van Eck, Fogliano, Galindo-Cuspinera, Scholten, & Stieger, 2019; van Eck, Hardeman, et al., 2019). Compared to a single food, oral processing behavior and sensory perception of food pairs are more complex depending on the specific food pair (van Eck, Fogliano, et al., 2019; van Eck, Hardeman, et al., 2019), and product sensory profiles change when foods are consumed in combination with other foods (Meinert et al., 2011; Paulsen et al., 2012).

Among food pairs, sauces, dips, gravies and condiments, i.e. salsa, ketchup, mayonnaise, and their companion foods, i.e. corn chips, French fries, breads, wraps, are commonly consumed food items contributing to substantial sodium intake in the Canadian diet (Health Canada, 2018a). In this study, the term condiment refers to sauces, dips, gravies and other prepared foodsdesigned to add flavor to foods (Bender, 2014), and the term carrier refers to the companion foods accompanying the condiments. The food industry has not met the target of sodium reduction for these food products (Health Canada, 2018b). Although a body of studies evaluated sensory attribute perception and/or consumer preference of sodium-reduced foods, few studies have investigated sensory perception of sodium-reduced condiments, and sensory assessments of sodium-reduced carriers have been performed without consideration of the presence of condiments. Understanding sensory perception and liking of sodium-reduced foods consumed with companion foods, specifically condiments and carriers, can aid successful development of sodium-reduced foods acceptable to consumers.

The objectives of this study were (1) to compare sensory profiles and overall liking between regular and sodium-reduced foods consumed with or without companion foods; and (2) to examine changes in sensory profiles and overall liking when foods are consumed with companion foods.

4.2. Materials and Methods

4.2.1. Participants

Regular consumers of the study products (age 18-59 years) were recruited on the University of Alberta campus (Edmonton, AB, Canada) to participate in 3 distinct consumer panels for the evaluation of 3 pairs of food products; 98 consumers (63% female) for salsa and corn chips, 100 consumers (69% female) for ketchup and tater tots (shaped and deep fried grated potato portions), and 98 consumers (70% female) for soy sauce and cooked rice (Table 4.1). Exclusion criteria included smoking and pregnancy. The study protocol was approved by a Research Ethics Board at the University of Alberta. Participants completed written informed consent and received a gift card in acknowledgement of their time and contribution to the study.

Table 4.1. Demographics and consumption frequency of study products for participants in 3 consumer panels for evaluation of 3 product pairs.

		Salsa & corn chips (n=98)	Ketchup & tater tots (n=100)	Soy sauce & cooked rice (n=98)
Gender, %	Male	36	30	29
	Female	63	69	70
	Other	1	1	1
Age, %	18-29 years	74	72	72
	30-39 years	18	21	17
	40-59 years	8	7	11
Food consumption frequency (%)				
		Corn chips	*French fries, tater tots or other fried potatoes*	*Cooked rice*
Once or less per month		41	19	2
2-3 times per month		35	43	14
1-2 times per week		16	25	23
3 or more times per week		8	13	61
		Salsa	*Ketchup*	*Soy sauce*
Once or less per month		42	21	22
2-3 times per month		25	35	30
1-2 times per week		21	22	19
3 or more times per week		12	22	29
		Corn chips with salsa	*Ketchup with French fries, tater tots or other fried potatoes*	*Soy sauce with cooked rice*
Once or less per month		56	28	48
2-3 times per month		25	40	29
1-2 times per week		15	22	15
3 or more times per week		4	10	8

4.2.2. Food samples and preparation

Three pairs of commonly consumed food products were selected to represent a range of regular and sodium-reduced food items available in the Canadian marketplace and commonly consumed in combination with companion foods; salsa and corn chips, tater tots and ketchup and cooked rice and soy sauce. Product information and sodium content are presented in Table 4.2.

Table 4.2. Food items for evaluation of 3 companion food pairs.

Product pair	Product item	Manufacturer	Ingredients	Sodium content
Salsa & corn chips	Regular corn chip	Frito Lay Canada, ON, Canada	Corn, vegetable oil, salt, calcium hydroxide	200 mg/ 50 g
	Sodium-reduced corn chips	Frito Lay Canada, ON, Canada	Corn, vegetable oil, salt, calcium hydroxide	140 mg/ 50 g
	Salsa	Frito Lay Canada, ON, Canada	Tomato puree, (water and tomato paste), diced tomatoes in tomato juice (contains calcium chloride, citric acid), jalapeño peppers, onions, vinegar, salt, garlic powder, natural flavour	250 mg/ 30 mL
Ketchup & tater tots	Regular ketchup	Heinz Canada, ON, Canada	Tomato paste (made from fresh ripe tomatoes), liquid sugars, white vinegar, salt, onion powder, spices.	140 mg/ 15 mL
	Sodium-reduced ketchup	Heinz Canada, ON, Canada	Tomato paste (made from fresh ripe tomatoes), liquid sugar, white vinegar, salt, potassium chloride, spices, flavours, onion powder, garlic powder.	60 mg/ 15 mL
	Tater tots	McCain Foods Limited, NB, Canada	Potatoes, vegetable oil (canola and/or soybean and/or cottonseed), corn starch, salt, dehydrated onion, sodium phosphate (to retain natural colour)	200 mg/ 85 g
Soy sauce & cooked rice	Regular soy sauce	Kikkoman Foods, Inc. , Wisconsin, USA	Water, wheat, soybeans, salt, sodium benzoate, brewing starter (*Aspergillus sojae*)	920 mg/ 15 mL
	Sodium-reduced soy sauce	Kikkoman Foods, Inc. , Wisconsin, USA	Water, wheat, soybeans, salt, lactic acid, sodium benzoate, brewing starter (*Aspergillus sojae*)	580 mg/ 15 mL
	Rice	Triple Girls Brand®, Vietnam	Long grain white rice	0

Four corn chips for each sample (approximately 1.4 g per chip) were served in 60 mL clear plastic cups with lids. Salsa was blended using an electric blender to generate a homogeneous texture before serving 40 mL samples in 60 mL clear plastic cups with lids. Rice was cooked (1/1 rice/water) in an electric rice cooker and 50 g samples were served in 125 mL clear jars with lids. Rice samples were kept at 60 ºC in a water bath before serving and placed on a hotplate during serving. Soy sauce samples (2.5 mL per sample) were served in 30 mL clear plastic cups with lids. Tater tots were baked following the manufacturer’s instruction and each tater tot was cut in half (approximately 4.5 g per piece). Eight pieces of tater tots were served in 118 mL Styrofoam cups with lids. Ketchup samples (30 mL per sample) were served in 60 mL clear plastic cups with lids. All samples were blinded with random 3-digit codes.

4.2.3. Sensory evaluation procedure

Participants of each consumer panel completed a tasting task and a questionnaire regarding their gender, age and consumption frequency of study foods through a 20-min session in individual sensory booths. For the tasting task, they evaluated 5 food samples, including the companion food alone (salsa, tater tots or cooked rice), the regular and sodium-reduced foods (corn chips, ketchup or soy sauce) without the companion food, and the regular and sodium-reduced foods with the companion food. Participants were provided with instructions to consistently apply condiments to carriers for simultaneous tasting of food pairs, applying about 5 mL of salsa on 1 whole chip, mixing a 2.5 mL soy sauce sample into a 50 g rice sample and fully dipping one tater tot piece into ketchup.

Participants rated the overall liking of each sample using 9-point hedonic scale ('Dislike extremely' to 'Like extremely') and sensory attribute intensities by using Rate-All-That-Apply (RATA) with 3-point scale (low, medium and high). RATA, a variation of the CATA (Check-All-That-Apply) question format, allows each consumer to rate the intensity of the applicable product attributes using a category scale (Ares et al., 2014). The sensory attribute list for each consumer panel (Table 4.3) was generated in a previous pilot study, in which 12 consumers tasted all samples and generated terms to describe differences between a regular product and its sodium-reduced counterpart consumed with and without the companion food.

Data were collected on tablets with the use of Compusense Cloud (Compusense, Guelph, ON, Canada). The sample orders were balanced among participants using Williams' Latin square designs. Participants were asked to cleanse their palate with distilled water and wait for one minute between samples, which was managed by a timer on the tablet screen.

4.2.4. Data analysis

RATA scores (0=None, 1=Low, 2=Medium, 3=High) were treated as continuous data, with not-applicable attributes treated as intensity of 0 (Ares et al., 2014; Meyners et al., 2016). For each consumer panel, linear mixed-effects models were performed for overall liking and sensory attribute intensities to examine if there were significant differences across the 5 food samples; with sample as a fixed effect and participant as a random effect. Tukey's HSD test was used for post-hoc pairwise comparisons of sample means. To describe food samples and associations between sensory attributes, Principle Component Analysis (PCA) was performed on sensory attribute data; we present the product space, in which each product is circled by a 95% confidence ellipse generated by virtual panels using Boostrap techniques, and a graph of a correlation circle of the sensory attributes for each consumer panel (Husson, Le, & Cadoret, 2017). PCA and Hierarchical Clustering on Principal Components (HCPC) analysis on liking data, with Euclidean distances and Ward's clustering method, were used to identify consumer segments with different product preferences (Husson, Josse, Le, & Mazet, 2018). All data analyses were carried out using R version 3.5.2 (R Core Team, 2018), *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2017), *FactoMineR* package (Husson et al., 2018) and *SensoMineR* package (Husson et al., 2017) at a significance value of $p \leq 0.05$.

4.3. Results and Discussion

4.3.1. Differences in sensory attributes between regular and sodium-reduced foods

When consumed with or without companion foods, consumers identified significant differences in sensory attribute intensity between regular and sodium-reduced corn chips and soy sauce, but not for ketchup (Table 4.3). Presence of the companion food did not affect saltiness

Table 4.3. Mean (standard deviation) for overall liking[1] and attribute intensity[2] obtained across three consumer panels for evaluation of 3 companion food pairs.

Product pair	Attribute	Samples				
Salsa & corn chips (n=98)		**Salsa**	**Regular chips**	**Sodium-reduced chips**	**Regular chips with salsa**	**Sodium-reduced chips with salsa**
	Liking	6.7a[3] (1.5)	7.1b (1.2)	7.0ab (1.2)	7.1ab (1.5)	7.2b (1.4)
	Salty	1.9a (0.8)	1.8a (0.8)	1.1c (0.6)	1.7a (0.7)	1.4b (0.8)
	Sweet	1.3a (0.8)	0.5b (0.7)	0.5b (0.7)	1.1a (0.7)	1.1a (0.7)
	Sour	1.5a (1.0)	0.2c (0.4)	0.1c (0.4)	1.3ab (1.0)	1.1b (0.9)
	Corn	0.4a (0.7)	2.1c (0.8)	2.1c (0.8)	1.7b (0.9)	1.7b (0.8)
	Tomato	2.4a (0.7)	0.1c (0.4)	0.1c (0.4)	2.0b (1.0)	2.1b (1.0)
	Spice	1.3a (0.9)	0.3c (0.6)	0.3c (0.5)	1.0b (0.8)	1.0b (0.8)
	Vinegar	1.4a (0.9)	0.2c (0.5)	0.2c (0.4)	1.1b (1.0)	1.1b (0.9)
	Onion	1.5a (0.8)	0.2c (0.4)	0.2c (0.5)	1.0b (0.8)	1.0b (0.7)
	Rancid	0.3a (0.6)	0.1bc (0.4)	0.1c (0.4)	0.3ab (0.5)	0.2abc (0.5)
	Hardness	0.3a (0.6)	1.6bc (0.7)	1.7c (0.7)	1.5bc (0.7)	1.5b (0.7)
	Crunchiness	0.4a (0.6)	2.4c (0.6)	2.4c (0.7)	2.1b (0.7)	2.2b (0.7)
	Graininess	0.7a (0.9)	1.5b (0.8)	1.6b (0.9)	1.4b (0.8)	1.4b (0.8)
Ketchup & tater tots (n=100)		**Tater tots**	**Regular ketchup**	**Sodium-reduced ketchup**	**Regular ketchup with tater tots**	**Sodium-reduced ketchup with tater tots**
	Liking	6.9a (1.3)	6.1bc (1.8)	5.9c (1.9)	6.5ab (1.7)	6.7a (1.6)
	Salty	1.1a (0.6)	1.3ab (0.8)	1.3ab (0.8)	1.4b (0.7)	1.4b (0.7)
	Sweet	0.7a (0.7)	1.9b (0.8)	2.0b (0.8)	2.0b (0.8)	1.8b (0.9)
	Sour	0.2a (0.5)	1.8bc (0.9)	2.0c (1.0)	1.7b (0.9)	1.6b (0.9)
	Metallic	0.2a (0.5)	0.6b (0.8)	0.8b (0.9)	0.6b (0.8)	0.6b (0.8)
	Potato	2.6a (0.6)	0.1c (0.4)	0.1c (0.4)	1.8b (0.9)	1.9b (0.9)
	Rancid	0.3 (0.6)	0.4 (0.7)	0.4 (0.7)	0.4 (0.7)	0.4 (0.7)
	Tomato	0.1a (0.3)	2.1b (0.9)	2.1b (0.8)	2.0b (0.8)	2.0b (0.8)
	Acidic	0.1a (0.4)	1.8c (0.8)	1.9c (0.9)	1.5b (0.9)	1.5b (0.9)
	Spice	0.3 (0.6)	0.7 (0.8)	0.8 (0.8)	0.6 (0.8)	0.7 (0.7)
	Greasy	1.5a (0.9)	0.3c (0.6)	0.3c (0.7)	0.9b (0.8)	0.9b (0.8)
	Astringent	0.3a (0.6)	0.8b (0.9)	0.8b (1.0)	0.7b (0.8)	0.7b (0.8)
	Thick	0.8 (0.9)	1.4 (0.9)	1.4 (1.0)	1.4 (0.9)	1.4 (0.9)
	Sour aftertaste	0.2a (0.5)	1.5b (1.0)	1.6b (1.0)	1.4b (0.9)	1.3b (1.0)
	Sweet aftertaste	0.6a (0.7)	1.6c (0.9)	1.4bc (0.9)	1.4bc (0.8)	1.3b (0.8)
	Metallic aftertaste	0.2 (0.5)	0.4 (0.7)	0.6 (0.9)	0.5 (0.7)	0.5 (0.8)
Soy sauce & cooked rice (n=98)		**Rice**	**Regular soy sauce**	**Sodium-reduced soy sauce**	**Regular soy sauce with rice**	**Sodium-reduced soy sauce with rice**
	Liking	6.6a (1.6)	5.1c (2.0)	5.5bc (1.8)	6.0b (1.8)	5.9b (1.7)
	Salty	0.2a (0.5)	2.6d (0.6)	2.2c (0.7)	2.2c (0.7)	1.8b (0.8)
	Sweet	0.8a (0.8)	0.6b (0.6)	0.8a (0.8)	0.8ab (0.7)	0.8ab (07)
	Sour	0.1a (0.3)	1.3bc (0.9)	1.4c (1.0)	1.1b (0.9)	1.4bc (0.9)
	Umami	0.4a (0.6)	1.5b (1.0)	1.5b (1.1)	1.4b (1.0)	1.3b (0.9)
	Bitter	0.1a (0.3)	0.9b (1.0)	0.8b (0.9)	0.7b (0.9)	0.7b (0.9)
	Fermented	0.2a (0.5)	1.2bc (1.0)	1.3c (1.0)	1.0b (0.9)	1.1bc (0.9)
	Acidic	0.1a (0.3)	1.3cd (1.0)	1.4d (0.9)	1.0b (0.8)	1.1bc (0.8)
	Vinegar	0.1a (0.3)	1.2bc (1.1)	1.3c (1.0)	1.0b (0.9)	1.1bc (0.9)
	Soft	1.9a (0.7)	0.4c (0.9)	0.4c (1.0)	1.6b (0.9)	1.7ab (0.9)
	Chewy	1.8a (0.7)	0.0b (0.3)	0.1b (0.4)	1.7a (0.9)	1.6a (0.9)
	Sticky	1.8 (0.8)	0.1 (0.4)	0.0 (0.1)	1.4 (0.9)	1.4 (1.0)
	Sour aftertaste	0.2a (0.4)	1.3c (1.1)	1.3bc (1.0)	1.0b (0.8)	1.1bc (0.9)
	Sweet aftertaste	0.9a (0.8)	0.5c (0.7)	0.6bc (0.7)	0.7abc (0.7)	0.8ab (0.8)

[1]: *9-point hedonic scale (from 1 = 'Dislike extremely' to 9 = 'Like extremely')*
[2]: *3-point RATA scale (0 = 'None', 1 =' Low', 2 = 'Medium', 3 = 'High')*
[3]: *Mean values within a row with different superscripts are significantly different according to Tukey's HSD test (p-value ≤ 0.05)*

discrimination between the regular and sodium-reduced products. Among evaluated attributes, *salty* was the single attribute differentiating the regular and sodium-reduced chips regardless of consuming with or without the salsa; the regular chips were *saltier* than the sodium-reduced chips. Similarly, the regular soy sauce was *saltier* than the sodium-reduced soy sauce consumed with or without the rice. Additionally, the sodium-reduced soy sauce was significantly *sweeter* than the regular soy sauce when consumed without rice. Consumers did not identify any significant attribute differences between the regular and sodium-reduced ketchups with or without tater tots.

Only the regular and sodium-reduced corn chips without salsa were significantly different in multiple attribute perception, evident by non-overlap ellipses around them in the PCA product space (Figure 4.1a, left). Corn chip attributes such as *corn*, *crunchiness*, *graininess* and *hardness* were highly positively correlated with each other and negatively correlated with *salty*; these attributes differentiated the regular and sodium-reduced chips without salsa. Despite significant attribute differences between regular and sodium-reduced products in univariate data analysis of the chips with salsa (for *salty*), the soy sauce (for *salty*, *sweet*), and the soy sauce with rice (for *salty*) (Table 4.3), these regular and sodium-reduced foods were not significantly different in multivariate data analysis (overlap confidence ellipses in Figure 4.1).

The current results suggest that consumer ability to identify sensory attribute differences between the regular and sodium-reduced products decreased in the presence of the companion foods, observed through the results of the univariate analysis for the soy sauce – rice pair and the results of multivariate analysis for the salsa – corn chips pair. Cherdchu & Chambers (2014) observed that carriers did not strongly affect the classification pattern of soy sauces, yet flavor differences among soy sauces of different brands were observed. van Eck, Fogliano, et al. (2019) suggested that consumer discrimination of foods was not influenced by the presence of the

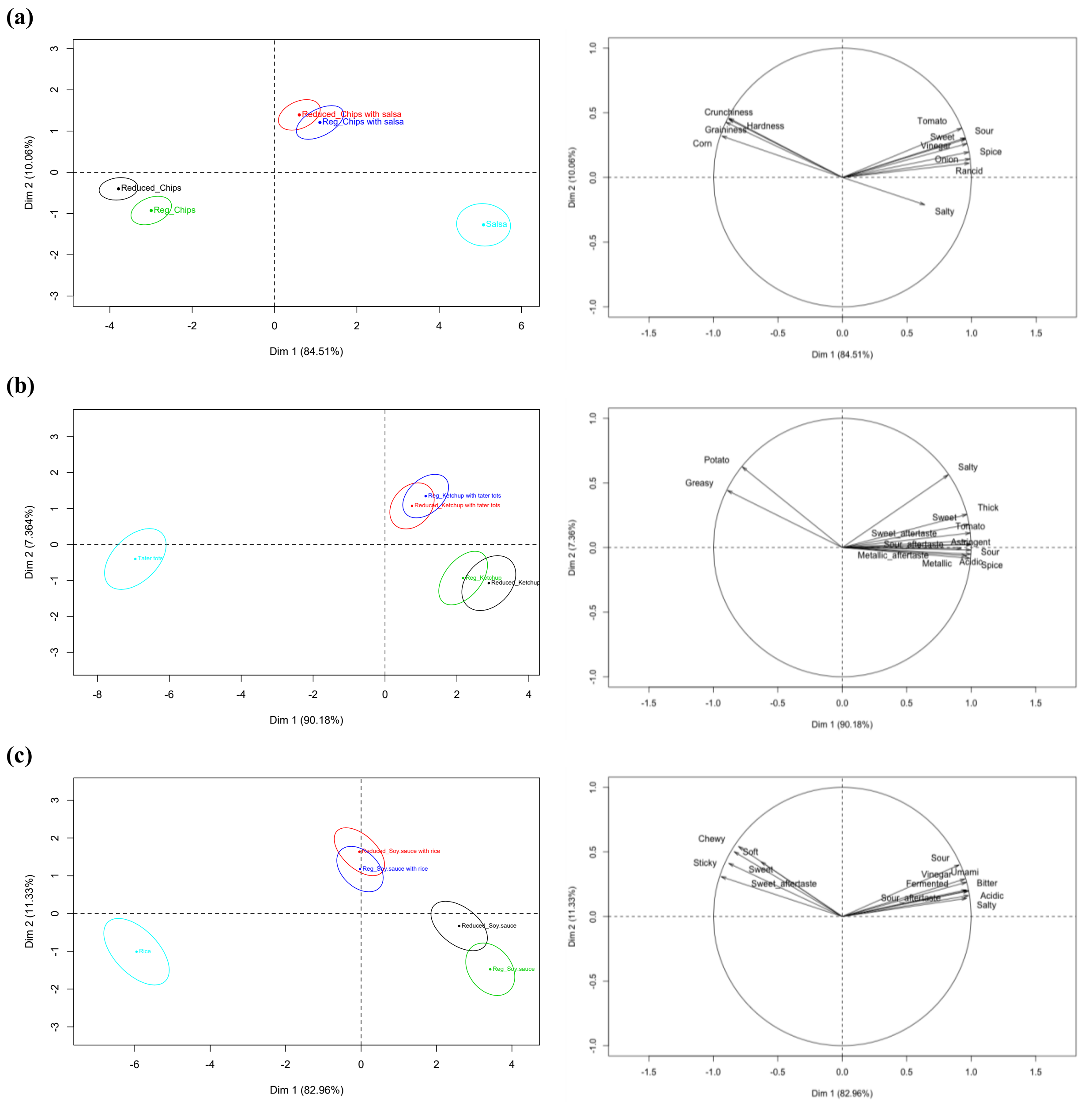


Figure 4.1. Principal Component Analysis (PCA) on RATA attribute intensities for (a) salsa and corn chips (n=98), (b) ketchup and tater tots (n=100), and (c) soy sauce and cooked rice (n=98); the map of samples with 95% confidence ellipses (Reg_: regular products, Reduced_: sodium-reduced products) on the left, the correlation circle of attributes on the right.

companion food if differences between foods were large, such as bread or carrot samples of different hardness consumed with mayonnaise. However, with smaller differences between foods, such as mayonnaise samples of different fat and viscosity levels, discrimination decreased and depended on the companion food type. Regular and sodium-reduced formulations of the same brand were used in this study, and the perceptible sensory differences were reduced when they were consumed with companion foods.

The use of the sodium replacer potassium chloride in the sodium-reduced ketchup (Table 4.2) helped to maintain sensory attribute intensities perceived by consumers; simple reduction in sodium content of corn chips and soy sauce without using sodium replacers decreased their perceived saltiness and increased soy sauce sweetness but did not affect other sensory attributes. Soy sauce is commonly used as a condiment as well as an ingredient in cooking recipes, hence, many studies have investigated the use of soy sauce as a sodium replacer to develop a range of sodium-reduced foods (Cho Long et al., 2015; Kremer et al., 2009, 2013; McGough et al., 2012; Xin Wei Goh et al., 2011). However, no previous studies have described differences in consumer sensory perception between regular and sodium-reduced formulations of the current products, corn chips, ketchup and soy sauce.

Consumers identified a limited number of sensory attribute differences between the commercial regular and sodium-reduced foods consumed with companion foods. In previous studies, the experimental research samples with tailored sodium levels were differentiated in various sensory attributes by trained panelists using Quantitative Descriptive Analysis (QDA) for most studies and consumers for some other studies, with the use of different descriptive consumer methods, including Free Listing (i.e. Dos Santos et al., 2015), Check-All-That-Apply (CATA) (i.e. Antúnez, Giménez, Alcaire, Vidal, & Ares, 2017), Flash Profile (FP) (Silow, Zannini, et al., 2016) and Ranking Descriptive Analysis (RDA) with consumers (i.e. Delgado-

Pando et al., 2018). Similarly, in the previous study (Chapter 2), with the use of RATA scale, we observed that commercially available regular and sodium-reduced food products were different in consumer perceived saltiness and several other sensory attributes for potato chips, dill pickles and ham, and different in all evaluated attributes for chicken noodle soup. Applying the RATA scale of the previous study to the current companion foods, consumers did not identify any differences between the commercial ketchups, perceived a difference in saltiness between the commercial corn chips, and differences in saltiness and sweetness between the commercial soy sauces.

4.3.2. Changes in sensory attributes when foods are consumed with companion foods

Both univariate (Table 4.3) and multivariate analysis (Figure 4.1) suggested that sensory attribute perception of each food in a condiment – carrier pair consumed together changed in different ways across food pairs.

The condiment and the carrier synergistically contributed to sensory perception of condiment – carrier pairs, with a greater influence of the condiment than the carrier for the ketchup – tater tots and soy sauce – rice pairs, but with equal influences for the salsa – corn chips pair. The ketchup dominated sensory perception of the ketchup – tater tots pair over tater tots while the soy sauce dominated sensory perception of the soy sauce – rice pair over the rice, evident by intensity increases of various condiment attributes when adding condiments to carriers compared to carriers alone (9 ketchup attributes and 8 soy sauce attributes) and intensity decreases of few condiment attributes compared to condiments alone (i.e. *sour*, *acidic* of ketchups, *salty* and *sour aftertaste* of the regular soy sauce, or *salty* of the sodium-reduced soy sauce) (Table 4.3). The presence of carriers enhanced the intensity of few carrier attributes, *potato* and *greasy* for the ketchup – tater tots pair, and *soft* and *chewy* for the soy sauce – rice pair. However, sensory attribute differences between corn chips with salsa and the salsa alone were comparable to sensory attribute differences between corn chips with salsa and corn chips alone, with changes in both salsa attributes and corn chip attributes (8 among 12 attributes). Moreover, a larger change was observed when adding salsa to the sodium-reduced than the regular chips; decreases in the intensity of *salty* and *sour* compared to salsa alone*,* and an increase in *saltiness* and a decrease in *hardness* compared to chips alone were observed only for sodium-reduced chips (Table 4.3).

The above univariate observations were in agreement with the results in PCA plots (Figure 4.1); sensory attribute perception of condiment – carrier pairs differed more from the carriers than the condiments for the ketchup – tater tots and soy sauce – rice pairs but not for the salsa – corn chips pair. The distance from the food pair to the carrier is greater than the distance from the food pair to the condiment in the product space for the ketchup – tater tots (Figure 4.1b, left) and soy sauce – rice pairs (Figure 4.1b, left). However, these two distances were comparable in the product space for the salsa – corn chips pair (Figure 4.1a, left). The graphs of attribute correlation (Figure 4.1, right) revealed two distinct groups of highly positively correlated attributes for evaluation of each food pair, condiment attributes (i.e. *tomato, sour, spice, onion* for salsa; *sweet*, *sour*, *tomato*, *spice*, *thick* for ketchup; *sour*, *umami*, *bitter*, *acidic*, *salty* for soy sauce) and carrier attributes (i.e. *crunchiness, hardness, graininess, corn* for corn chips; *potato*, *greasy* for tater tots; *chewy*, *sticky*, *soft*, *sweet* for rice). The two attribute groups were negatively correlated with each other and correlated to dimension 1 (carrier characteristics on the left, condiment characteristics on the right), thus differentiating sensory perception of carriers, condiment-carrier pairs and condiments.

The current results also suggested that condiments drove flavor attribute perception (salsa, ketchup or soy sauce flavors) while carriers drove texture/mouthfeel attribute perception (i.e. *hardness, crunchiness* and *graininess* for the corn chips, *greasy* for the tater tots, *soft* and *chewy* for the rice), a finding which aligns with previous studies (van Eck, Fogliano, et al., 2019; van Eck, Hardeman, et al., 2019) and suggests a priority selection of the sensory modality for future sensory studies of these food products. Intensity decreases of texture attributes (i.e. *crunchiness* and *hardness* for corn chips) when adding condiments to carriers was due to moisture incorporation. Condiments influenced the oral processing behavior (structural transitions), hence, influenced the sensory perception of the carriers (van Eck, Hardeman, et al., 2019). Similarly, Cherdchu & Chambers (2014) suggested that solid carriers (i.e. white rice, grilled chicken) tended to modify sensory properties of soy sauce more than liquid carriers (i.e. chicken broth). The texture of carriers rather than the flavor complexity of carriers had the greatest impact on sensory perception of food combinations in the current study, observed through the modification of texture attributes when adding soy sauce to rice and salsa to corn chips.

Although decreases in sensory attribute intensities of carriers and increases in sensory attribute intensities of condiments when consumed together were reported in previous studies (Cherdchu & Chambers, 2014; Meinert et al., 2011; Paulsen et al., 2012; Traynor et al., 2013; van Eck, Fogliano, et al., 2019; van Eck, Hardeman, et al., 2019), there have been no reports of regular and sodium-reduced foods consumed with companion foods. The changes in sensory attributes of sodium-reduced foods consumed with companion foods reveals the need to perform sensory studies of sodium-reduced foods as food pairs rather than single foods for successful reformulation of sodium-reduced foods. Moreover, companion foods affected both static and temporal sensory perception of food pairs (van Eck, Fogliano, et al., 2019). As food pairings are particular cases of meals, research into food pairings is best performed within meal contexts (Lahne, 2018). Therefore, further studies of other sodium-reduced foods and comparisons between consumer methods (i.e. temporal sensory profiling such as Temporal Dominance of Sensations (TDS) or Temporal Check-All-That-Apply (TCATA)), or testing in real contexts (i.e. Home Use Test) or simulated contexts such as Virtual Reality, would be useful to confirm the current findings and aid selection of the most appropriate method for use in development of sodium-reduced companion foods.

4.3.3. Overall liking and consumer segments

There was no difference in overall liking between the regular and sodium-reduced products consumed with or without the companion food within each food pair (Table 4.3); perceived differences in sensory attributes between the regular and sodium-reduced companion products were acceptable to consumers, demonstrating that sodium reduction in a range of condiments and foods consumed with companion foods is promising.

Presence of the companion food influenced the liking of regular and sodium-reduced foods differently within and across food pairs (Table 4.3), revealing that the selection of appropriate companion foods is important to evaluation of consumer liking. The salsa – corn chips and ketchup – tater tots pairs were appropriate combinations for consumer evaluation of these products; the food pair was liked equally or more than individual foods consumed on its own. Similarly, the cooked rice was an appropriate carrier for the soy sauce; food pairs were liked equally or more than soy sauces alone. However, soy sauces with rice were less liked than the rice alone. Salsa with corn chips and ketchup with tater tots are common food pairs for Canadian consumers while cooked rice is normally consumed with many other food components, not only soy sauce.

The HCPC analysis of liking data revealed 3 consumer clusters for each food pair (Figure 4.2). Mean liking of consumer clusters are shown in Figure 4.3. As the current objective of the HCPC analysis was to identify possible consumer heterogeneity, we kept the suggested consumer segments with uneven sample sizes from the HCPC outputs, with a small participant number for Cluster 1 (n=12) in the salsa – corn chips pair and Cluster 2 (n=9) in the ketchup – tater tots pair. Therefore, the linear mixed-effects ANOVA model was not used on the data of each consumer segment to compare each of liking and sensory attributes between samples. The detailed description of each consumer segment by categorial variables (age, gender, food consumption frequency) and quantitative variables (sensory attributes) through R outputs is presented in the Appendix 3; this section focuses only on differences between clusters. The graphs of product liking correlation from PCA (Figure 4.2, right) describe the gradient of liking that opposes consumers who like all samples (on the right) from those who dislike all samples (on the left). Consumers are also differentiated by product liking correlated to the second dimension; i.e. for the salsa – corn chips combination (Figure 4.2a, right), some consumers liked the regular and sodium-reduced chips but disliked the salsa (Cluster 1).

Consumer segments of different product liking were not associated with age or gender but they differed in sensory attribute perception (Appendix 3). The regular and sodium-reduced foods consumed with or without companion foods differed in mean liking for Cluster 1 (n=12) of the salsa – corn chips pair, Cluster 1 (n=29) and Cluster 2 (n=9) of the ketchup – tater tots pair, and Cluster 2 (n=45) for the soy sauce with salsa pair more than the other consumer segments within each food pair. The presence of companion foods also changed mean liking of these consumer segments (Figure 4.3). For the salsa – corn chips pair (Figure 4.3a), consumers of Cluster 1 disliked the salsa; although they liked the regular and sodium-reduced chips comparable to the other segments, adding salsa to chips strongly decreased their liking. For the ketchup – tater tots pair (Figure 4.3b), consumers of Cluster 1 preferred the regular to sodium-reduced ketchup, they liked the tater tots, and adding the ketchup to tater tots decreased their liking. On the contrary, consumers of Cluster 2 preferred the sodium-reduced to regular ketchup with or without tater tots and disliked the tater tots. Cluster 2 of the soy sauce – rice pair had a greater mean liking for the sodium-reduced than regular soy sauce without rice, but consumers of this segment preferred the regular over the sodium-reduced soy sauce with rice (Figure 4.3c).

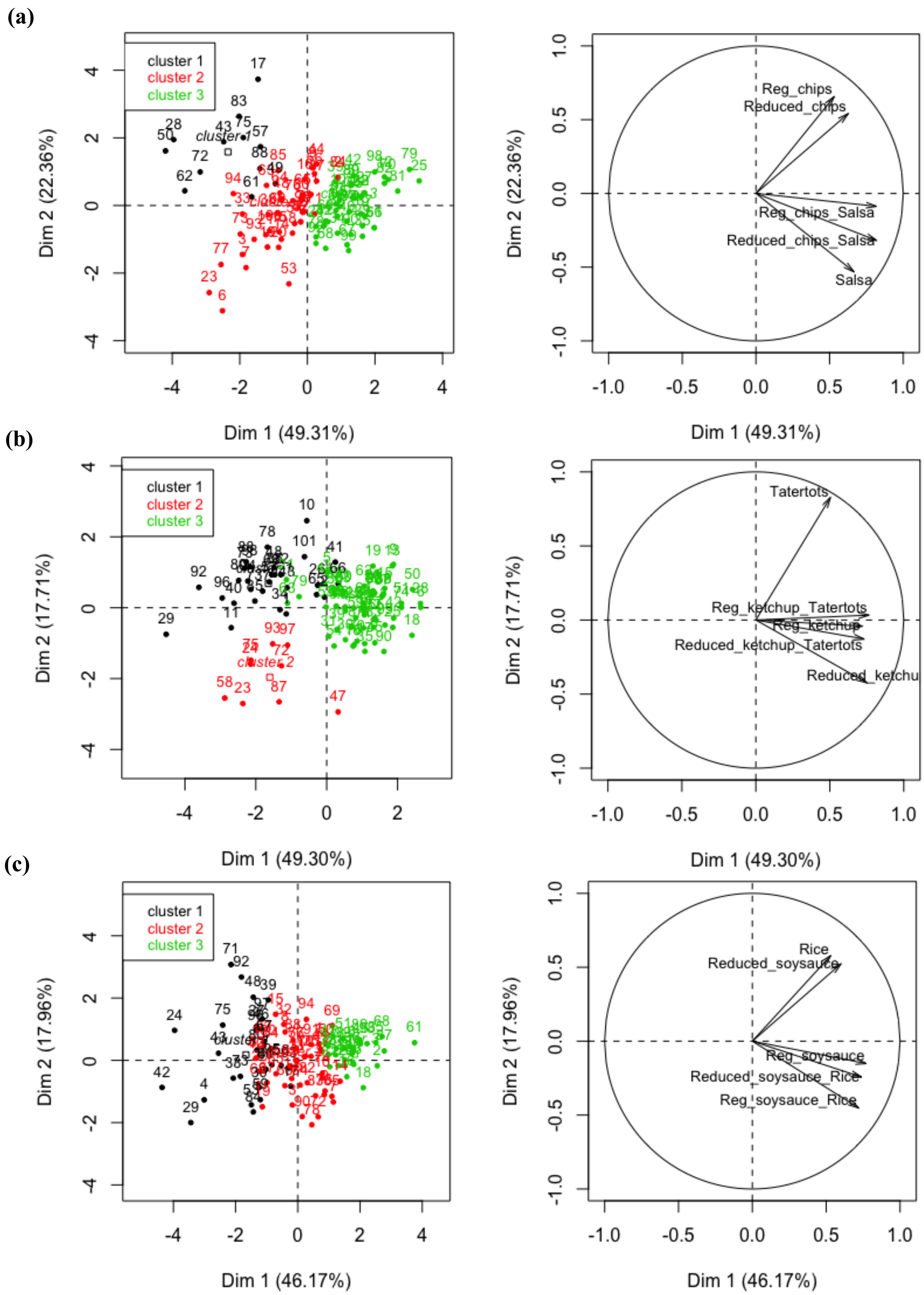


Figure 4.2. Principal Component Analysis (PCA) and Hierarchical Clustering on Principal Components (HCPC) analysis on liking data for (a) salsa and corn chips (n1=12, n2=41, n3=44), (b) ketchup and tater tots (n1=29, n2=9, n3=62), and (c) soy sauce and cooked rice (n1=28, n2=45, n3=25); the map of consumer clusters on the left, the correlation circle of product liking on the right (Reg_: regular products, Reduced_: sodium-reduced products).

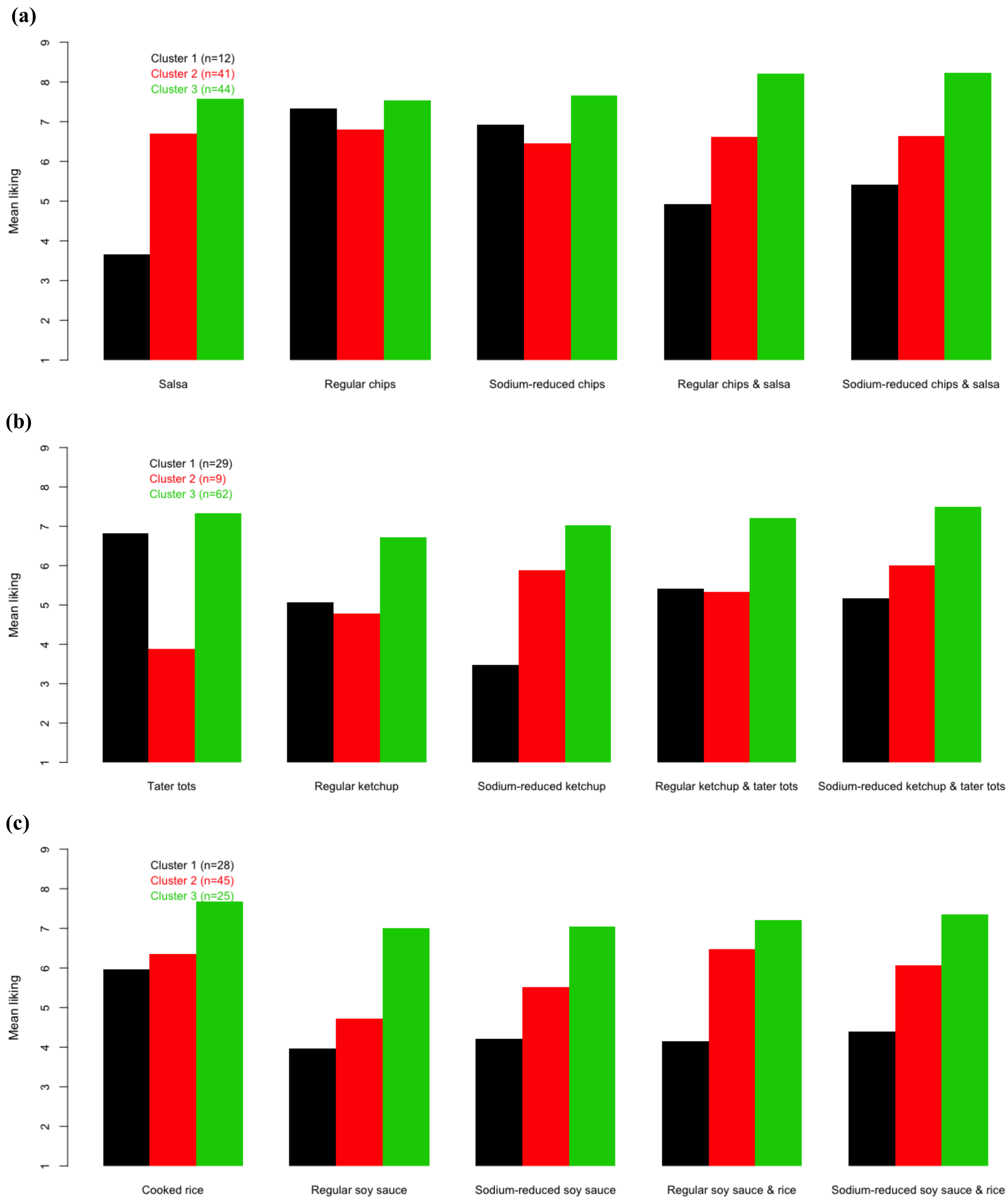


Figure 4.3. Mean liking of consumer clusters obtained by Hierarchical Clustering on Principal Components (HCPC) analysis on liking data for (a) salsa and corn chips, (b) ketchup and tater tots, and (c) soy sauce and cooked rice.

Consumer segments differed in sensory attribute perception (Appendix 3), such as *crunchiness* and *salty* of the regular and sodium-reduced corn chips without salsa, *bitter* of regular soy sauce with and without rice, and various attributes of ketchup and tater tots. Compared to other segments, Cluster 3 consumers of the ketchup – tater tots pair, who liked all 5 samples more than the other clusters, perceived greater intensity of *tomato* in the sodium-reduced ketchup, lower intensity of *astringent* and *acidic* in the regular ketchup, and lower intensity of *acidic, metallic, sour* and *astringent* of the sodium-reduced ketchup with tater tots. Contrary to Cluster 3, Cluster 1 consumers, who liked ketchup samples less than the other clusters (both the regular and sodium-reduced ketchup, with and without tater tots), perceived greater intensity of *sour* and *acidic* in ketchup samples and *sour aftertaste, metallic, greasy* and *astringent* in the sodium-reduced ketchup with tater tots. The opposing sensory attribute perception and liking suggested that attributes such as *sour, acidic, metallic* and *astringent* contributed to consumer disliking of the ketchup samples.

Food consumption frequency influenced consumer sensory perception and liking of sodium-reduced foods consumed with companion foods; consumers who had greater liking scores of all 5 samples than other consumers (Cluster 3 in each panel) consumed the study foods more frequently. Consumer segments were associated with consumption frequency of corn chips with salsa (*p-value* = 0.016, Appendix 3); consumers who liked all samples (Cluster 3, Figure 4.3a) were significantly associated with the frequent consumption of corn chips (*3 times or more per week*) and corn chips with salsa (*1-2 times per week*) while the other two segments were negatively associated with the frequent consumption of salsa (Cluster 1, *2-3 times per month*, *p-value* = 0.03) or corn chips (Cluster 2 *more than 3 times per week*, *p-value* = 0.01). However, no such associations were observed for the ketchup – tater tots pair. Although there were no significant associations between consumer segments and the food consumption frequency for evaluation of the soy sauce – rice pairs, the consumption frequency of soy sauce at *2-3 times per month* was negatively associated with Cluster 2 (*p-value* = 0.005) and positively associated with Cluster 3 (*p-value* = 0.007). This may be due to the similarity in hedonic response among 3 consumer segments, especially Cluster 1 and Cluster 3; Cluster 2 was the single consumer segment with changing mean liking with the addition of rice to the soy sauce.

Consumer heterogeneity in response to sodium reduction in foods was also reported by Antúnez, Giménez, Alcaire, Vidal, & Ares (2019) and the previous study (Chapter 2). Antúnez et al. (2019) suggested 2 consumer segments of different hedonic responses to rice samples of a range of added salt levels; consumers who preferred higher salt contents and showed higher hedonic sensitivity to salt reduction were more willing to add salt to foods and less willing to reduce sodium intake. In the previous study (Chapter 2), 3 consumer segments of consumption frequencies (low, medium and high) of commonly consumed dietary sodium sources differed in sensory attribute perception and liking of sodium-reduced foods.

Knowledge of consumer segment characteristics can aid development of sodium-reduced foods acceptable to targeted consumer segments. Consumer sensory perception and preference are influenced by inter-individual differences (Köster & Mojet, 2018); several consumer attributes such as taste sensitivity, demographics, body mass index (BMI), health status, sodium intake and usual consumption of dietary sodium sources have been studied for their potential association with sensory perception and liking for salt taste (Hayes et al., 2010; McLean, 2014; Zandstra et al., 2016) and sodium-reduced foods (Antúnez et al., 2019; Chapter 2). Although the current results suggested that food consumption frequency may influence sensory perception and liking of sodium-reduced companion foods, a food frequency questionnaire (FFQ) regarding consumption frequency of common dietary sodium sources (Chapter 2) would be useful to confirm this influence. In the previous study (Chapter 2), the influence of the overall consumption level of common dietary sodium sources was significant while we observed no associations between consumption frequency of study products and consumer sensory perception and liking of sodium-reduced foods. Segmentation of consumers by consumers' attributes, i.e. PROP sensitivity (Hayes et al., 2010), consumption habits (Antúnez et al., 2019; Chapter 2), and/or health status (Mente et al., 2018) could provide insights about their sensory perception and liking for sodium-reduced companion foods.

4.4. Conclusions

Consumer sensory perception and liking of regular and sodium-reduced foods consumed with companion foods has not been presented in the literature. The presence of the companion food did not affect salty intensity discrimination between the regular and sodium-reduced foods but reduced consumer ability to discriminate multiple sensory attribute perceptions between the regular and sodium-reduced foods. However, sensory differences between the regular and sodium-reduced foods were acceptable to consumers, suggesting that sodium-reduction in a range of companion foods is promising. Sensory perception and consumer liking changed when foods were consumed with companion foods, confirming the need to perform sensory studies on food pairs rather than single foods for successful reformulation of sodium-reduced foods. Condiments drove flavor attributes while carriers drove texture/mouthfeel attributes of food pairs, revealing a priority selection of the sensory modality for sensory studies on food pairs. Consumer heterogeneity of hedonic response to sodium reduction in companion foods confirmed the challenge to please every consumer. Further studies on other sodium-reduced companion food items, characterization of consumer segments and comparisons of consumer methods would be useful to confirm the current findings and aid development of sodium-reduced companion foods acceptable to targeted consumer segments.

4.5. References

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2017). Consumer perception of salt-reduced breads: Comparison of single and two-bites evaluation. *Food Research International*, *100*(July), 254–259. https://doi.org/10.1016/j.foodres.2017.07.014

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2019). Consumers' heterogeneity towards salt reduction: Insights from a case study with white rice. *Food Research International*, *121*(March), 48–56. https://doi.org/10.1016/j.foodres.2019.03.007

Ares, G., Bruzzone, F., Vidal, L., Cadena, R. S., Giménez, A., Pineau, B., … Jaeger, S. R. (2014). Evaluation of a rating-based variant of check-all-that-apply questions: Rate-all-that-apply (RATA). *Food Quality and Preference*, *36*, 87–95. https://doi.org/10.1016/j.foodqual.2014.03.006

Bender, D. A. (2014). *A dictionary of food and nutrition*. Oxford University Press. Retrieved from https://www-oxfordreference-com.login.ezproxy.library.ualberta.ca/view/10.1093/acref/9780191752391.001.0001/acref-9780191752391

Cappuccio, F. P., Beer, M., & Strazzullo, P. (2019). Population dietary salt reduction and the risk of cardiovascular disease. A scientific statement from the European Salt Action Network. *Nutrition, Metabolism and Cardiovascular Diseases*, *29*(2), 107–114. https://doi.org/10.1016/j.numecd.2018.11.010

Cherdchu, P., & Chambers, E. (2014). Effect of carriers on descriptive sensory characteristics: A case study with soy sauce. *Journal of Sensory Studies*. https://doi.org/10.1111/joss.12100

Cho Long, L., Soh Min, L., & Kwang-Ok, K. (2015). Use of consumer acceptability as a tool to determine the level of sodium reduction: a case study on beef soup substituted with potassium chloride and soy-sauce odor. *Journal of Food Science*, *80*(11), S2570–S2577. https://doi.org/10.1111/1750-3841.13098

Delgado-Pando, G., Fischer, E., Allen, P., Kerry, J. P., O'Sullivan, M. G., & Hamill, R. M. (2018). Salt content and minimum acceptable levels in whole-muscle cured meat products. *Meat Science*, *139*(January), 179–186. https://doi.org/10.1016/j.meatsci.2018.01.025

Dos Santos, B. A., Bastianello Campagnol, P. C., da Cruz, A. G., Galvão, M. T. E. L., Monteiro, R. A., Wagner, R., & Pollonio, M. A. R. (2015). Check all that apply and free listing to describe the sensory characteristics of low sodium dry fermented sausages: Comparison with trained panel. *Food Research International*, *76*(Part 3), 725–734. https://doi.org/10.1016/j.foodres.2015.06.035

Galmarini, M. V, Dufau, L., Loiseau, A. L., Visalli, M., & Schlich, P. (2018). Wine and cheese: two products or one association? A new method for assessing wine-cheese pairing. *Beverages, 2306-5710*, *4*(1), 13. https://doi.org/10.3390/beverages4010013

Hayes, J. E., Sullivan, B. S., & Duffy, V. B. (2010). Explaining variability in sodium intake through oral sensory phenotype, salt sensation and liking. *Physiology and Behavior*, *100*(4), 369–380. https://doi.org/10.1016/j.physbeh.2010.03.017

Health Canada. (2018a). Sodium intake of Canadians in 2017. Retrieved from https://www.canada.ca/en/health-canada/services/publications/food-nutrition/sodium-intake-canadians-2017.html

Health Canada. (2018b). *Sodium reduction in processed foods in Canada: An evaluation of progress toward voluntary targets from 2012 to 2016*. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/legislation-guidelines/guidance-documents/guidance-food-industry-reducing-sodium-processed-foods-progress-report-2017.html

Husson, F., Josse, J., Le, S., & Mazet, J. (2018). FactoMineR: Multivariate exploratory data analysis and data mining. R package. https://doi.org/10.1201/b10345-2

Husson, F., Le, S., & Cadoret, M. (2017). SensoMineR: Sensory data analysis. R package. https://doi.org/10.1111/j.1745-459X.2007.00137.x

Inguglia, E. S., Zhang, Z., Tiwari, B. K., Kerry, J. P., & Burgess, C. M. (2017). Salt reduction strategies in processed meat products – A review. *Trends in Food Science & Technology*, *59*, 70–78. https://doi.org/10.1016/j.tifs.2016.10.016

Israr, T., Rakha, A., Sohail, M., Rashid, S., & Shehzad, A. (2016). Salt reduction in baked products: Strategies and constraints. *Trends in Food Science and Technology*, *51*, 98–105. https://doi.org/10.1016/j.tifs.2016.03.002

Jaenke, R., Barzi, F., McMahon, E., Webster, J., & Brimblecombe, J. (2017). Consumer acceptance of reformulated food products: A systematic review and meta-analysis of salt-reduced foods. *Critical Reviews in Food Science and Nutrition*, *57*(16), 3357–3372. https://doi.org/10.1080/10408398.2015.1118009

Köster, E., & Mojet, J. (2018). Complexity of consumer perception. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 1: New approaches to classic methods* (Vol. 1, pp. 23–45). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102089-0.00002-9

Kremer, S., Mojet, J., & Shimojo, R. (2009). Salt reduction in foods using naturally brewed soy sauce. *Journal of Food Science*, *74*(6), S255–S262. https://doi.org/10.1111/j.1750-3841.2009.01232.x

Kremer, S., Shimojo, R., Holthuysen, N., Köster, E. P., & Mojet, J. (2013). Consumer acceptance of salt-reduced "soy sauce" foods over rapidly repeated exposure. *Food Quality and Preference*, *27*(2), 179–190. https://doi.org/10.1016/j.foodqual.2012.06.002

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*. https://doi.org/10.18637/jss.v082.i13

Lahne, J. (2018). Evaluation of meals and food pairing. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 2: Alternative approaches and special applications* (1st ed., Vol. 2, pp. 85–107). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-101743-2.00004-2

McGough, M. M., Sato, T., Rankin, S. A., & Sindelar, J. J. (2012). Reducing sodium levels in frankfurters using naturally brewed soy sauce. *Meat Science*, *91*(1), 69–78. https://doi.org/10.1016/j.meatsci.2011.12.008

McLean, R. M. (2014). Measuring population sodium intake: A review of methods. *Nutrients*, *6*(11), 4651–4662. https://doi.org/10.3390/nu6114651

Meinert, L., Frøst, M. B., Bejerholm, C., & Aaslyng, M. D. (2011). Enhancing the sensory quality of vegetables by decreasing some less-desired sensory properties with low-fat pork gravy. *Journal of Culinary Science and Technology*, *9*(2), 113–131. https://doi.org/10.1080/15428052.2011.584496

Mente, A., O'Donnell, M., Rangarajan, S., McQueen, M., Dagenais, G., Wielgosz, A., … Yusuf, S. (2018). Urinary sodium excretion, blood pressure, cardiovascular disease, and mortality: a community-level prospective epidemiological cohort study. *The Lancet*, *392*(10146), 496–506. https://doi.org/10.1016/S0140-6736(18)31376-X

Meyners, M., Jaeger, S. R., & Ares, G. (2016). On the analysis of Rate-All-That-Apply (RATA) data. *Food Quality and Preference*, *49*, 1–10. https://doi.org/10.1016/j.foodqual.2015.11.003

Paulsen, M. T., Ueland, Ø., Nilsen, A. N., Öström, Å., & Hersleth, M. (2012). Sensory perception of salmon and culinary sauces - An interdisciplinary approach. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2011.09.004

R Core Team. (2018). R: A language and environment for statistical computing. *R Foundation for Statistical Computing, Vienna, Austria*. Retrieved from https://www.r-project.org/

Silow, C., Zannini, E., Axel, C., Lynch, K. M., & Arendt, E. K. (2016). Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, *89*, 330–337. https://doi.org/10.1016/j.foodres.2016.08.031

Traynor, M. P., Burke, R., O'Sullivan, M. G., Hannon, J. A., & Barry-Ryan, C. (2013). Sensory and chemical interactions of food pairings (basmati rice, bacon and extra virgin olive oil) with banana. *Food Research International*, *54*(1), 569–577. https://doi.org/10.1016/j.foodres.2013.07.050

van Eck, A., Fogliano, V., Galindo-Cuspinera, V., Scholten, E., & Stieger, M. (2019). Adding condiments to foods: How does static and dynamic sensory perception change when bread and carrots are consumed with mayonnaise? *Food Quality and Preference*, *73*(November 2018), 154–170. https://doi.org/10.1016/j.foodqual.2018.11.013

van Eck, A., Hardeman, N., Karatza, N., Fogliano, V., Scholten, E., & Stieger, M. (2019). Oral processing behavior and dynamic sensory perception of composite foods: Toppings assist saliva in bolus formation. *Food Quality and Preference*, *71*(March 2018), 497–509. https://doi.org/10.1016/j.foodqual.2018.05.009

World Health Organization. (2016). *The SHAKE technical package for salt reduction*. Retrieved from http://www.who.int/dietphysicalactivity/publications/shake-salt-habit/en/

Xin Wei Goh, F., Itohiya, Y., Shimojo, R., Sato, T., Hasegawa, K., & Lai Peng, L. (2011). Using naturally brewed soy sauce to reduce salt in selected foods. *Journal of Sensory Studies*, *26*(6), 429–435.

Zandstra, E. H., Lion, R. R., & Newson, R. S. (2016). Salt reduction: Moving from consumer awareness to action. *Food Quality and Preference*, *48*, 376–381. https://doi.org/10.1016/j.foodqual.2015.03.005

Chapter 5. General discussion and conclusions

This PhD research combined a suite of methods to study both consumer sensory perception and liking in response to sodium reduction in processed foods. A range of commercially available regular and sodium-reduced paired foods, including single foods (Chapter 2; Chapter 3) and companion foods (Chapter 4), were compared for JAR saltiness (Chapter 2), RATA sensory profiles (Chapter 2; Chapter 4), TDS and TCATA temporal sensory profiles (Chapter 3) and hedonic rating (Chapter 2; Chapter 4). Moreover, this research studied consumer heterogeneity in sensory perception and liking of regular and sodium-reduced foods and the influences of inter-individual consumer differences including consumer sensory acuity through a salt threshold test and taster status test, consumption frequency of study products and overall consumption frequency of dietary sodium food sources through a DSS-FFQ questionnaire (Chapter 2; Chapter 4). Comparisons across products and sensory methods are useful for generalization of the study findings and can provide a guide for further applications of study methods to other food products. Knowledge of differences in consumer sensory perception and liking between commercially available regular and sodium-reduced products and the consumer heterogeneity in response to sodium reduction in processed foods may aid development of sodium-reduced foods acceptable to targeted consumer segments.

5.1. Static and temporal sensory profiles of sodium-reduced foods

Sodium reduction influenced product sensory profiles differently across food products and sensory methods. Commercially available regular and sodium-reduced products were different in the intensity of salty taste and several other sensory attributes for potato chips, dill pickles and ham, and in all evaluated attributes for chicken noodle soup (Chapter 2). However, consumers identified a limited number of sensory attribute differences between the commercial regular and sodium-reduced foods consumed with companion foods; consumers did not identify any differences between the commercial ketchups, perceived a difference in saltiness between the commercial corn chips, and differences in saltiness and sweetness between the commercial soy sauces (Chapter 4). Presence of the companion food reduced consumer ability to discriminate sensory attributes between regular and sodium-reduced products but did not affect saltiness discrimination between the regular and sodium-reduced products (Chapter 4).

Changes in temporal sensory profiles between sodium-reduced food products compared to their conventional counterparts differed across products and between temporal methods. More participants characterized regular products as *salty* compared to the number of participants who characterized sodium-reduced products as *salty* throughout the temporal evaluation of potato chips and cream of mushroom soup for both TDS and TCATA methods and intakes, and throughout temporal evaluation of ham except for TCATA across modalities. The opposite effect was observed for canned corn. Static perception of a sensory attribute may not differ between a regular and sodium-reduced product, but its temporal perception may be changed, i.e. *potato* and *dry* of potato chips, *metallic* and *bitter* of ham (Chapter 3).

The difference in static or temporal sensory perception between regular and sodium-reduced foods may be due to flavor interactions and/or ingredient changes required for food reformulation. Sodium-reduced pickles and ham with potassium chloride as a salt substitute were perceived as less intense in saltiness and several sensory attributes compared to the regular products (Chapter 2). However, salt replacement by potassium chloride helped to maintain sensory attribute intensities of sodium-reduced ketchup (Chapter 4). Potassium chloride induces *metallic* and *bitter* off-taste in processed meats (Gaudette & Pietrasik, 2017; Greiff et al., 2015; Inguglia et al., 2017), which was observed through temporal evaluation of the regular and sodium-reduced ham (Chapter 3). The interaction between *sweet* and *salty* tastes was observed in the temporal evaluation of canned corn; sweetness suppresses salty taste and other basic tastes at moderate concentrations, and sodium enhances sweetness at low concentrations (Keast & Breslin, 2003). Sodium-reduced corn was characterized as *salty* by more participants than the regular corn in both TDS and TCATA profiles. Additionally, the interactions between salty, sweet, sour and bitter were observed in the static evaluation of ketchup. Bitterness was suppressed by salt while salt taste was not affected by bitterness, and sourness at medium intensity suppresses bitterness (Keast & Breslin, 2003). Salty, sweet and sour tastes may mask bitterness elicited by potassium chloride and also decreased saltiness in the sodium-reduced ketchup, resulting no perceived differences in sensory attributes between regular and sodium-reduced ketchups (Chapter 4). Sodium plays an important role in water holding capacity of meat protein; texture attributes of cooked ham, particularly *juiciness*, changed with sodium reduction with the use of salt replacers as observed in previous studies (i.e. Gaudette & Pietrasik, 2017; Greiff et al., 2015). Sodium reduction reformulation with changes in several ingredients lead to changes in all evaluated attributes of chicken noodle soup (Chapter 2) and cream of mushroom soup (Chapter 3). Although an increase in viscosity can be used to improve saltiness of a sodium-reduced oil-in-water soup (Busch et al., 2013; Cornelia et al., 2016; Lima et al., 2018), the regular and sodium-reduced cream of mushroom soups were characterized differently in many sensory attributes throughout the evaluation time, not only texture attributes related to viscosity such as *creamy, thick, thin* but also flavor attributes such as *salty, cream flavor, mushroom* and *umami* (Chapter 3).

The findings of this research suggest a thorough consideration of the appropriate sensory methods for sensory description and differentiation of regular and sodium-reduced products in future studies. The 3-point RATA scale is an appropriate tool for static sensory profiling of regular and sodium-reduced food products (Chapter 2, Chapter 4). In previous studies, various sensory attributes of research samples with tailored sodium levels were differentiated by trained panelists using QDA, and by consumers using descriptive consumer methods (Antúnez et al., 2017, 2016; Costa et al., 2018; Delgado-Pando et al., 2018; Dos Santos et al., 2015; Fellendorf et al., 2015, 2016; Henrique et al., 2015; Silow, Zannini, et al., 2016). This is the first application of RATA to sensory profiling of sodium-reduced foods; sensory differences between commercial regular and sodium-reduced products were detected by a consumer panel between products in which differences are minimized to maintain consumer acceptability. For temporal sensory profiling, TDS provided a detailed description of attribute changes and differentiation of the sensory profiles between regular and sodium-reduced products. TCATA profiles were more consistent across intakes than TDS profiles, suggesting that single-intake evaluation could be representative of TCATA profiles over repeated consumption. Multi-intake evaluation can help identify the effect of adaptation and build-up of attribute intensity through repeated exposure of the product (Jamieson & Watling, 2017), observed by masking of the *heated oil* attribute by the intense salty taste built up from multiple intakes in TDS evaluation of potato chips (Chapter 3). Temporal evaluation across modalities may be appropriate for detailed description of regular and sodium-reduced ham, and temporal evaluation by modality may be appropriate for identification of significant differences between the regular and sodium-reduced foods.

5.2. Consumer liking of sodium-reduced foods

Consumer acceptance of sensory differences between regular and sodium-reduced foods varies according to specific products (Chapter 2; Chapter 4; Jaenke et al., 2017). The perceptible sensory differences between regular and sodium-reduced foods were acceptable to consumers for potato chips, cooked ham, corn chips and soy sauce; the decreased intensity in saltiness and/or several sensory attributes in these sodium-reduced products did not change their overall liking. Saltiness decrease contributed to an increase in pickle liking while the decreased intensity of all evaluated sensory attributes of the sodium-reduced chicken noodle soup was associated with a decrease in consumer liking.

Although there was no consumer preference between regular and sodium-reduced foods consumed with companion foods, the presence of the companion food influenced the liking for each of regular and sodium-reduced foods, revealing that the selection of appropriate companion foods is important in the evaluation of consumer liking for these products, particularly condiments and carriers (Chapter 4). Sodium reduction levels are achieved differently across product types without changing consumer acceptability (Jaenke et al., 2017); limited data are available in the literature regarding consumer preference between the regular and sodium-reduced products evaluated in this research. Reformulated cooked ham is reported to be acceptable to consumers at a range of sodium reduction levels depending on the salt replacers used to achieve the sodium reduction (Inguglia et al., 2017; Jaenke et al., 2017), i.e. 30% sodium reduction without changing consumer liking in the study of Pietrasik & Gaudette (2014). Willems et al. (2011) reported similar results for preference of chicken noodle soup; the 22%- and 32%-sodium-reduced chicken noodle soups were less liked than the regular-salt soup by 646 French consumers.

5.3. Consumer heterogeneity in response to sodium reduction in processed foods

It is important to note a large heterogeneity in consumer response to sodium reduction in processed foods (Chapter 2; Chapter 4; Antúnez et al., 2019), confirming the food industry challenge to please every consumer with a single formulation. The penalty analysis in Chapter 2 revealed that lower saltiness decreased product liking for some participants but increased it for others, which may result in non-significant differences in mean liking between the regular and sodium-reduced products averaged across all participants. Thus, three consumer segments stratified by consumption frequency of dietary sodium sources (DSS) (Chapter 2) differed in sensory attribute perception and product liking of the study food products. Similarly, differences in product sensory attribute perception were observed among three consumer segments of different liking of regular and sodium-reduced foods consumed with companion foods (Chapter 4). Consumer heterogeneity in purchase intention of sodium-reduced processed meats were reported by Shan et al. (2017) and Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Adasme-Berríos (2019).

Knowledge of consumer segment characteristics can aid development of sodium-reduced foods acceptable to targeted consumer segments. It is evident that usual consumption frequency of DSS influences intensity perception of salt taste and other attributes in foods, and unique liking drivers are identified for different consumer segments, i.e. *flavorful* of potato chips and *umami* of chicken noodle soup for the segment of consumers who frequently consumed dietary sodium sources (Chapter 2). Although consumers are largely aware of the negative health effects of high salt intake (Newson et al., 2013), it is difficult for them to reduce salt in their diet. Consumers add salt to foods at the table if food products are lower in salt intensity than desired (Liem, Miremadi, et al., 2012). Therefore, it is necessary to consider the usual sodium intake as well as consumption habit of the target market segment for successful reformulation of sodium-reduced foods. Supertasters may perceive greater intensity of salty taste and other sensory attributes (Chapter 2; Hayes et al., 2010) and perceive greater changes in sensory perception and liking with increasing sodium levels in foods (Hayes et al., 2010) compared to tasters and non-tasters. Although there were no associations between observed individual salt detection threshold with sensory attribute perception and liking (Chapter 2; Lucas, Riddell, Liem, Whitelock, & Keast, 2011; Mitchell et al., 2013), DSS group threshold values increased along with the increasing consumption frequency of DSS (Chapter 2). Segmentation of consumers by consumers' attributes, i.e. PROP sensitivity (Chapter 2; Hayes et al., 2010), consumption habits

(Chapter 3; Antúnez et al., 2019), the level of interest in sodium reduction and health (Liem, Toraman Aydin, et al., 2012; Vázquez et al., 2009; Zandstra et al., 2018) and/or health status (Mente et al., 2018) could provide insights about their sensory perception and liking for sodium-reduced foods. Moreover, gradual sodium reduction in targeted foods could be the best accepted strategy to reduce dietary sodium intake as it enables consumers to adapt to decreasing levels of sodium in foods (Bobowski et al., 2015; Willems et al., 2013; Zandstra et al., 2018). Consumer segments of high, moderate and low DSS consumption frequency may be gradually merged into a single target segment through their decreasing sodium intake.

5.4. Limitations and future research

Commercial food products used in this research represent formulations currently available in the market. No sodium-reduced formulations for a few staple food items contributing to substantial dietary sodium were available for evaluation, i.e. bread, cereals and bakery products, cheese and dairy products (Health Canada, 2018b; Kloss et al., 2015). Further application of the study methods to research formulations or available products in other countries may assist the global food industry to meet sodium reduction targets by generating knowledge of consumer sensory perception and acceptance and identifying consumer liking drivers to aid development of sodium-reduced foods acceptable to targeted consumer segments.

TDS and TCATA profiles differed in their level of detailed description and differentiation of the regular and sodium-reduced foods (Chapter 3), but temporal profiles were not evaluated in association with participants' hedonic perception; therefore, it was not possible to determine whether the additional significant differences between the regular and sodium-reduced products identified by TDS relative to TCATA contribute to consumer preference. Further studies comparing TDS and TCATA in association with consumer hedonic perception would be useful to confirm the current findings and identify drivers of liking, and aid selection of the appropriate temporal method for use in sodium-reduced food product development. Moreover, applying temporal sensory profiling to sodium-reduced companion foods could provide insights into temporal sensory changes and identification of liking drivers for each consumer segment (Paulsen, Naes, Ueland, Rukke, & Hersleth, 2013; van Eck, Fogliano, et al., 2019; van Eck, Hardeman, et al., 2019).

Although temporal profiling with multi-intake evaluation or evaluation across modalities might provide a representative description of consumer sensory experiences during actual consumption of food products, they provided different results from single intake evaluation (Chapter 4; Galmarini et al., 2017) or evaluation by modality respectively (Chapter 4; Monaco et al., 2014; Nguyen et al., 2018; Varela et al., 2018). Several findings were generated from the multi-intake evaluation of two different food items, the potato chips as a solid food and the cream of mushroom soup as a liquid food, and the comparison between evaluation across modalities and by modality for cooked ham (Chapter 4). Further applications of these methods to products of different flavor and texture complexity are needed to confirm the current findings then support selection of the most appropriate temporal method for each food type.

Sensory perception and liking of sodium-reduced foods may be influenced by inter-individual differences (Chapter 3; Chapter 5; Antúnez et al., 2019; Bobowski et al., 2015; Hayes et al., 2010). The observations at aggregate level of all participants in this research and most previous studies may omit information of the influence of sensory perception on product liking within a consumer segment. Although consumer segmentation was performed in this research, a larger number of participants for each consumer segment is needed to confirm the current findings and should be used in future studies.

Consumer perception and preference is also influenced by the consumption environment (Köster & Mojet, 2018); research into sodium-reduced foods is best performed within meal contexts. Studies in this research and most previous studies were performed in sensory booths (CLT); obtained liking scores may not represent perceived liking in real contexts, i.e. consumption in home. CLT and HUT provided different results of consumer perception (Boutrolle et al., 2005, 2007); Willems et al. (2013) reported that initial liking in CLT did not predict liking after repeated in-home consumption of sodium-reduced soups, with higher scores in HUT than CLT. However, consumers may have added more or less water according to manufacturer's instruction or added salt/flavor enhancers to sodium-reduced soups in HUT, as observed by Liem, Miremadi, et al. (2012) for table salt use. Research under realistic context with more control is necessary to confirm the current findings, i.e. use of the virtual environment (VR).

FOP labelling with nutrition claims can create negative sensory expectation, decrease perceived liking, then decrease the selection of sodium-reduced foods, especially for taste-oriented consumers (Appendix 1). FOP labelling with the use of nutritional warnings on high sodium products has been effective in decreasing sodium content of food products by food manufacturers (Health Canada, 2017; Kanter, Reyes, Swinburn, Vandevijvere, & Corvalán, 2019; Lima, 2017; Ministry of Health Israel, 2017) as well as increasing consumer choice of sodium-reduced foods (Ares et al., 2018; Machín, Curutchet, Giménez, Aschemann-Witzel, & Ares, 2019; Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Adasme-Berríos, 2019; Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Lobos, 2019; Tórtora et al., 2019). Further studies on the influence of nutritional warnings on expected and perceived sensory attributes and liking will be useful to confirm the effectiveness of nutritional warnings and encourage governments to implement this type of FOP labelling to reduce global dietary sodium intake.

5.5. Conclusions

Sodium reduction influenced consumer sensory perception and liking differently across food products and sensory methods. For commercially available single foods, regular and sodium-reduced products differed in static and temporal sensory profiles, not only salty taste but also other sensory attributes. However, consumers identified a limited number of sensory attribute differences between the commercial regular and sodium-reduced foods consumed with companion foods, salty taste for the corn chips, salty and sweet tastes for the soy sauce, but no significant differences for ketchup. Presence of the companion food reduced consumer ability to discriminate sensory attributes between regular and sodium-reduced products but did not affect saltiness discrimination between the regular and sodium-reduced products. Static perception of a sensory attribute may not differ between a regular and sodium-reduced product, but the temporal perception may be different.

The perceptible sensory differences between regular and sodium-reduced foods were acceptable to consumers for potato chips, cooked ham, corn chips and soy sauce. The sodium-reduced pickles were liked more than the regular pickles while the sodium-reduced chicken noodle soup was liked less than the regular soup. Although there was no consumer preference between regular and sodium-reduced foods consumed with companion foods, the presence of the companion food influenced the liking for each of regular and sodium-reduced foods. There was consumer heterogeneity in response to sodium reduction in processed foods, confirming the food industry challenge to please every consumer with a single formulation. Consumption frequency of dietary sodium sources (DSS) influenced consumer sensory perception and liking. Unique liking drivers can be identified for each consumer segment. The knowledge of consumer sensory perception and liking of commercial regular and sodium-reduced food pairs and consumer heterogeneity in response to sodium reduction in processed foods can aid the food industry in development of sodium-reduced food formulations acceptable to targeted consumer segments.

Moreover, comparisons across food products and sensory methods can guide selection of the most appropriate method to describe and discriminate consumer sensory perception between regular and sodium-reduced products. The 3-point RATA scale is an appropriate tool for static sensory profiling of regular and sodium-reduced food products. TDS provided a more detailed description than TCATA of attribute changes and differentiation of the temporal sensory profiles between regular and sodium-reduced products. TCATA profiles were more consistent across intakes than TDS profiles. The temporal evaluation by modality may provide a less detailed description and identify more differences between the regular and sodium-reduced ham than the temporal evaluation across modalities.

5.6. References

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2017). Consumer perception of salt-reduced breads: Comparison of single and two-bites evaluation. *Food Research International*, *100*(July), 254–259. https://doi.org/10.1016/j.foodres.2017.07.014

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2019). Consumers' heterogeneity towards salt reduction: Insights from a case study with white rice. *Food Research International*, *121*(March), 48–56. https://doi.org/10.1016/j.foodres.2019.03.007

Antúnez, L., Giménez, A., & Ares, G. (2016). A consumer-based approach to salt reduction: Case study with bread. *Food Research International*, *90*, 66–72. https://doi.org/10.1016/j.foodres.2016.10.015

Ares, G., Aschemann-Witzel, J., Curutchet, M. R., Antúnez, L., Machín, L., Vidal, L., & Giménez, A. (2018). Product reformulation in the context of nutritional warning labels: Exploration of consumer preferences towards food concepts in three food categories. *Food Research International*, *107*, 669–674. https://doi.org/10.1016/j.foodres.2018.03.021

Bobowski, N., Rendahl, A., & Vickers, Z. (2015). A longitudinal comparison of two salt reduction strategies: Acceptability of a low sodium food depends on the consumer. *Food Quality and Preference*, *40*(PB), 270–278. https://doi.org/10.1016/j.foodqual.2014.07.019

Boutrolle, I., Arranz, D., Rogeaux, M., & Delarue, J. (2005). Comparing central location test and home use test results: Application of a new criterion. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2005.03.015

Boutrolle, I., Delarue, J., Arranz, D., Rogeaux, M., & Köster, E. P. (2007). Central location test vs. home use test: Contrasting results depending on product type. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2006.06.003

Busch, J. L. H. C., Yong, F. Y. S., & Goh, S. M. (2013). Sodium reduction: Optimizing product composition and structure towards increasing saltiness perception. *Trends in Food Science and Technology*, *29*(1), 21–34. https://doi.org/10.1016/j.tifs.2012.08.005

Cornelia, M., Triyanti, I., Prasetia, T., & Purnomo, C. (2016). Sensory evaluation and characterizations of emulsion containing sodium chloride and its application in corn soup. *Jurnal Teknologi Dan Industri Pangan*, *27*(2), 157–164. https://doi.org/10.6066/jtip.2016.27.2.157

Costa, R. G. B., Alves, R. C., Cruz, A. G. da, Sobral, D., Teodoro, V. A. M., Costa Junior, L. C. G., … Miguel, E. M. (2018). Manufacture of reduced-sodium Coalho cheese by partial replacement of NaCl with KCl. *International Dairy Journal*, *87*, 37–43. https://doi.org/10.1016/j.idairyj.2018.07.012

Delgado-Pando, G., Fischer, E., Allen, P., Kerry, J. P., O'Sullivan, M. G., & Hamill, R. M. (2018). Salt content and minimum acceptable levels in whole-muscle cured meat products. *Meat Science*, *139*(January), 179–186. https://doi.org/10.1016/j.meatsci.2018.01.025

Dos Santos, B. A., Bastianello Campagnol, P. C., da Cruz, A. G., Galvão, M. T. E. L., Monteiro, R. A., Wagner, R., & Pollonio, M. A. R. (2015). Check all that apply and free listing to describe the sensory characteristics of low sodium dry fermented sausages: Comparison with trained panel. *Food Research International*, *76*(Part 3), 725–734. https://doi.org/10.1016/j.foodres.2015.06.035

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding. *Meat Science*, *103*, 75–82. https://doi.org/10.1016/j.meatsci.2014.12.010

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016). Effect of using ingredient replacers on the physicochemical properties and sensory quality of low-salt and low-fat white puddings. *European Food Research and Technology*, *242*(12), 2105–2118. https://doi.org/10.1007/s00217-016-2707-z ER

Galmarini, M. V., Loiseau, A.-L. L., Debreyer, D. D. D., Visalli, M., & Schlich, P. (2017). Use of multi-intake Temporal Dominance of Sensations (TDS) to evaluate the influence of wine on cheese perception. *Journal of Food Science*, *82*(11), 2669–2678. https://doi.org/10.1111/1750-3841.13932

Gaudette, N. J., & Pietrasik, Z. (2017). The sensory impact of salt replacers and flavor enhancer in reduced sodium processed meats is matrix dependent. *Journal of Sensory Studies*, *32*(1), 1–11. https://doi.org/10.1111/joss.12247

Greiff, K., Mathiassen, J. R., Misimi, E., Hersleth, M., Aursand, I. G., Ekrem, M., … Aursand, I. G. (2015). Gradual reduction in sodium content in cooked ham, with corresponding change in sensorial properties measured by sensory evaluation and a multimodal Machine vision system. *PLoS ONE*, *10*(9), 1–15. https://doi.org/10.1371/journal.pone.0137805

Hayes, J. E., Sullivan, B. S., & Duffy, V. B. (2010). Explaining variability in sodium intake through oral sensory phenotype, salt sensation and liking. *Physiology and Behavior*, *100*(4), 369–380. https://doi.org/10.1016/j.physbeh.2010.03.017

Health Canada. (2017). *Front-of-Package nutrition labelling: September 18, 2017 Stakeholder engagement meeting*. Retrieved from https://www.canada.ca/en/services/health/publications/food-nutrition/labelling-stakeholder-engagement-meeting-september-2017.html

Health Canada. (2018). *Sodium reduction in processed foods in Canada: An evaluation of progress toward voluntary targets from 2012 to 2016*. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/legislation-guidelines/guidance-documents/guidance-food-industry-reducing-sodium-processed-foods-progress-report-2017.html

Henrique, N. A., Deliza, R., & Rosenthal, A. (2015). Consumer Sensory Characterization of Cooked Ham Using the Check-All-That-Apply (CATA) Methodology. *Food Engineering Reviews*, *7*(2), 265–273. https://doi.org/10.1007/s12393-014-9094-7

Inguglia, E. S., Zhang, Z., Tiwari, B. K., Kerry, J. P., & Burgess, C. M. (2017). Salt reduction strategies in processed meat products – A review. *Trends in Food Science & Technology*, *59*, 70–78. https://doi.org/10.1016/j.tifs.2016.10.016

Jaenke, R., Barzi, F., McMahon, E., Webster, J., & Brimblecombe, J. (2017). Consumer acceptance of reformulated food products: A systematic review and meta-analysis of salt-reduced foods. *Critical Reviews in Food Science and Nutrition*, *57*(16), 3357–3372. https://doi.org/10.1080/10408398.2015.1118009

Jamieson, L., & Watling, E. (2017). Multiple-ingestion Time-Intensity. In *Time-dependent measures of perception in sensory evaluation* (pp. 321–342). Retrieved from %3CGo

Kanter, R., Reyes, M., Swinburn, B., Vandevijvere, S., & Corvalán, C. (2019). The food supply prior to the implementation of the chilean law of food labeling and advertising. *Nutrients*, *11*(1), 1–10. https://doi.org/10.3390/nu11010052

Keast, R. S. J., & Breslin, P. A. S. (2003). An overview of binary taste-taste interactions. *Food Quality and Preference*, *14*(2), 111–124. https://doi.org/10.1016/S0950-3293(02)00110-6

Kloss, L., Meyer, J. D., Graeve, L., & Vetter, W. (2015). Sodium intake and its reduction by food reformulation in the European Union - A review. *NFS Journal*, *1*, 9–19. https://doi.org/10.1016/j.nfs.2015.03.001

Köster, E., & Mojet, J. (2018). Complexity of consumer perception. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 1: New approaches to classic methods* (Vol. 1, pp. 23–45). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102089-0.00002-9

Liem, D. G., Miremadi, F., Zandstra, E. H., & Keast, R. S. (2012). Health labelling can influence taste perception and use of table salt for reduced-sodium products. *Public Health Nutrition*, *15*(12), 2340–2347. https://doi.org/10.1017/s136898001200064x

Liem, D. G., Toraman Aydin, N., & Zandstra, E. H. (2012). Effects of health labels on expected and actual taste perception of soup. *Food Quality and Preference*, *25*(2), 192–197. https://doi.org/10.1016/j.foodqual.2012.02.015

Lima, A., Dufauret, M., le Révérend, B., Wooster, T. J., le Reverend, B., & Wooster, T. J. (2018). Deconstructing how the various components of emulsion creamers impact salt perception. *Food Hydrocolloids*, *79*, 310–318. https://doi.org/10.1016/j.foodhyd.2018.01.005

Lima, F. (2017). *Peru publishes warning manual for processed product food labels*. Retrieved from https://gain.fas.usda.gov/Recent GAIN Publications/Peru Publishes Warning Manual for Processed Product Food Labels_Lima_Peru_9-27-2017.pdf

Lucas, L., Riddell, L., Liem, D. G., Whitelock, S., & Keast, R. (2011). The influence of sodium on liking and consumption of salty food. *Journal of Food Science*, *76*(1). https://doi.org/10.1111/j.1750-3841.2010.01939.x

Machín, L., Curutchet, M. R., Giménez, A., Aschemann-Witzel, J., & Ares, G. (2019). Do nutritional warnings do their work? Results from a choice experiment involving snack products. *Food Quality and Preference*, *77*(May), 159–165. https://doi.org/10.1016/j.foodqual.2019.05.012

Mente, A., O'Donnell, M., Rangarajan, S., McQueen, M., Dagenais, G., Wielgosz, A., … Yusuf, S. (2018). Urinary sodium excretion, blood pressure, cardiovascular disease, and mortality: a community-level prospective epidemiological cohort study. *The Lancet*, *392*(10146), 496–506. https://doi.org/10.1016/S0140-6736(18)31376-X

Ministry of Health Israel. (2017). Food label and nutritional labeling. Retrieved June 28, 2019, from https://www.health.gov.il/English/Topics/FoodAndNutrition/Nutrition/Adequate_nutrition/Pages/labeling.aspx

Mitchell, M., Brunton, N. P., & Wilkinson, M. G. (2013). The influence of salt taste threshold on acceptability and purchase intent of reformulated reduced sodium vegetable soups. *Food Quality and Preference*, *28*(1), 356–360. https://doi.org/10.1016/j.foodqual.2012.11.002

Monaco, R. di, Chengcheng, S., Masi, P., & Cavella, S. (2014). Temporal dominance of sensations: a review. *Trends in Food Science & Technology*, *38*(2), 104–112.

Newson, R. S., Elmadfa, I., Biro, G., Cheng, Y., Prakash, V., Rust, P., … Feunekes, G. I. J. (2013). Barriers for progress in salt reduction in the general population. An international study. *Appetite*, *71*, 22–31. https://doi.org/10.1016/j.appet.2013.07.003

Nguyen, Q. C., Næs, T., & Varela, P. (2018). When the choice of the temporal method does make a difference: TCATA, TDS and TDS by modality for characterizing semi-solid foods. *Food Quality and Preference*, *66*(December 2017), 95–106. https://doi.org/10.1016/j.foodqual.2018.01.002

Paulsen, M. T., Naes, T., Ueland, O., Rukke, E.-O., & Hersleth, M. (2013). Preference mapping of salmon-sauce combinations: The influence of temporal properties. *Food Quality and Preference*, *27*(2), 120–127. https://doi.org/10.1016/j.foodqual.2012.09.010

Pietrasik, Z., & Gaudette, N. J. (2014). The impact of salt replacers and flavor enhancer on the processing characteristics and consumer acceptance of restructured cooked hams. *Meat Science*, *96*(3), 1165–1170. https://doi.org/10.1016/j.meatsci.2013.11.005

Schnettler, B., Ares, G., Sepúlveda, N., Bravo, S., Villalobos, B., Hueche, C., & Adasme-Berríos, C. (2019). How do consumers perceive reformulated foods after the implementation of nutritional warnings? Case study with frankfurters in Chile. *Food Quality and Preference*, *74*(December 2018), 179–188. https://doi.org/10.1016/j.foodqual.2019.01.021

Schnettler, B., Ares, G., Sepúlveda, N., Bravo, S., Villalobos, B., Hueche, C., & Lobos, G. (2019). Are consumers willing to pay more for reformulated processed meat products in the context of the implementation of nutritional warnings? Case study with frankfurters in Chile. *Meat Science*, *152*(February), 104–108. https://doi.org/10.1016/j.meatsci.2019.02.007

Shan, L. C., De Brún, A., Henchion, M., Li, C., Murrin, C., Wall, P. G., & Monahan, F. J. (2017). Consumer evaluations of processed meat products reformulated to be healthier – A conjoint analysis study. *Meat Science*, *131*, 82–89. https://doi.org/10.1016/j.meatsci.2017.04.239

Silow, C., Zannini, E., Axel, C., Lynch, K. M., & Arendt, E. K. (2016). Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, *89*, 330–337. https://doi.org/10.1016/j.foodres.2016.08.031

Tórtora, G., Machín, L., & Ares, G. (2019). Influence of nutritional warnings and other label features on consumers' choice: Results from an eye-tracking study. *Food Research International*, *119*(September 2018), 605–611. https://doi.org/10.1016/j.foodres.2018.10.038

van Eck, A., Fogliano, V., Galindo-Cuspinera, V., Scholten, E., & Stieger, M. (2019). Adding condiments to foods: How does static and dynamic sensory perception change when bread and carrots are consumed with mayonnaise? *Food Quality and Preference*, *73*(November 2018), 154–170. https://doi.org/10.1016/j.foodqual.2018.11.013

van Eck, A., Hardeman, N., Karatza, N., Fogliano, V., Scholten, E., & Stieger, M. (2019). Oral processing behavior and dynamic sensory perception of composite foods: Toppings assist saliva in bolus formation. *Food Quality and Preference*, *71*(March 2018), 497–509. https://doi.org/10.1016/j.foodqual.2018.05.009

Varela, P., Antúnez, L., Carlehög, M., Alcaire, F., Castura, J. C., Berget, I., … Ares, G. (2018). What is dominance? An exploration of the concept in TDS tests with trained assessors and consumers. *Food Quality and Preference*, *64*. https://doi.org/10.1016/j.foodqual.2017.10.014

Vázquez, M. B., Curia, A., & Hough, G. (2009). Sensory descriptive analysis, sensory acceptability and expectation studies on biscuits with reduced added salt and increased fiber. *Journal of Sensory Studies*, *24*(4), 498–511. https://doi.org/10.1111/j.1745-459X.2009.00223.x

Willems, A. A., Van Hout, D. H. A., Zijlstra, N., & Zandstra, E. H. (2013). Effects of salt labelling and repeated in-home consumption on long-term liking of reduced-salt soups. *Public Health Nutrition*, *17*(5), 1130–1137. https://doi.org/10.1017/S1368980013001055

Zandstra, E. H., Willems, A. A., & Lion, R. (2018). Making salt-reduced products more appealing to consumers: impact of front-of-pack messages on liking and table salt use over time. *Public Health Nutrition*, *21*(15), 2762–2772. https://doi.org/10.1017/S1368980018001714

BIBLIOGRAPHY

Aaslyng, M. D., Vestergaard, C., & Koch, A. G. (2014). The effect of salt reduction on sensory quality and microbial growth in hotdog sausages, bacon, ham and salami. *Meat Science*, *96*(1), 47–55. https://doi.org/10.1016/j.meatsci.2013.06.004

Allison, A., & Fouladkhah, A. (2018). Adoptable interventions, human health, and food safety considerations for reducing sodium content of processed food products. *Foods*, *7*(2), 16. https://doi.org/10.3390/foods7020016

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2017). Consumer perception of salt-reduced breads: Comparison of single and two-bites evaluation. *Food Research International*, *100*(July), 254–259. https://doi.org/10.1016/j.foodres.2017.07.014

Antúnez, L., Giménez, A., Alcaire, F., Vidal, L., & Ares, G. (2019). Consumers' heterogeneity towards salt reduction: Insights from a case study with white rice. *Food Research International*, *121*(March), 48–56. https://doi.org/10.1016/j.foodres.2019.03.007

Antúnez, L., Giménez, A., & Ares, G. (2016). A consumer-based approach to salt reduction: Case study with bread. *Food Research International*, *90*, 66–72. https://doi.org/10.1016/j.foodres.2016.10.015

Antúnez, L., Giménez, A., Vidal, L., & Ares, G. (2018). Partial replacement of NaCl with KCl in bread: Effect on sensory characteristics and consumer perception. *Journal of Sensory Studies*, *33*(5), 1–12. https://doi.org/10.1111/joss.12441

Arcand, J., Jefferson, K., Schermel, A., Shah, F., Trang, S., Kutlesa, D., … Abbe, M. R. L. (2016). Examination of food industry progress in reducing the sodium content of packaged foods in Canada : 2010 to 2013. *Appl. Physiol. Nutr. Metab.*, *41*(April), 1–7. https://doi.org/dx.doi.org/10.1139/apnm-2015-0617

Ares, G., Alcaire, F., Antúnez, L., Vidal, L., Giménez, A., & Castura, J. C. (2017). Identification of drivers of (dis)liking based on dynamic sensory profiles: Comparison of Temporal Dominance of Sensations and Temporal Check-all-that-apply. *Food Research International*, *92*, 79–87. https://doi.org/10.1016/j.foodres.2016.12.016

Ares, G., Aschemann-Witzel, J., Curutchet, M. R., Antúnez, L., Machín, L., Vidal, L., & Giménez, A. (2018). Product reformulation in the context of nutritional warning labels:

Exploration of consumer preferences towards food concepts in three food categories. *Food Research International*, *107*, 669–674. https://doi.org/10.1016/j.foodres.2018.03.021

Ares, G., Bruzzone, F., Vidal, L., Cadena, R. S., Giménez, A., Pineau, B., … Jaeger, S. R. (2014). Evaluation of a rating-based variant of check-all-that-apply questions: Rate-all-that-apply (RATA). *Food Quality and Preference*, *36*, 87–95. https://doi.org/10.1016/j.foodqual.2014.03.006

Ares, G., Castura, J. C., Antúnez, L., Vidal, L., Giménez, A., Coste, B., … Jaeger, S. R. (2016). Comparison of two TCATA variants for dynamic sensory characterization of food products. *Food Quality and Preference*, *54*, 160–172. https://doi.org/10.1016/j.foodqual.2016.07.006

Ares, G., Jaeger, S. R., Antúnez, L., Vidal, L., Giménez, A., Coste, B., … Castura, J. C. (2015). Comparison of TCATA and TDS for dynamic sensory characterization of food products. *Food Research International*, *78*, 148–158. https://doi.org/10.1016/j.foodres.2015.10.023

Barbieri, G., Barbieri, G., Bergamaschi, M., Francheschini, M., & Berizi, E. (2016). Reduction of NaCl in cooked ham by modification of the cooking process and addition of seaweed extract (Palmaria palmata). *LWT - Food Science and Technology*, *73*, 700–706. https://doi.org/10.1016/j.lwt.2016.06.057

Bartoshuk, L. M., Duffy, V. B., & Miller, I. J. (1994). PTC/PROP tasting: Anatomy, psychophysics, and sex effects. *Physiology and Behavior*, *56*(6), 1165–1171. https://doi.org/10.1016/0031-9384(94)90361-1

Bender, D. A. (2014). *A dictionary of food and nutrition*. Oxford University Press. Retrieved from https://www-oxfordreference-com.login.ezproxy.library.ualberta.ca/view/10.1093/acref/9780191752391.001.0001/acref-9780191752391

Bobowski, N., Rendahl, A., & Vickers, Z. (2015). A longitudinal comparison of two salt reduction strategies: Acceptability of a low sodium food depends on the consumer. *Food Quality and Preference*, *40*(PB), 270–278. https://doi.org/10.1016/j.foodqual.2014.07.019

Boeckner, L. S., Pullen, C. H., Walker, S. N., Abbott, G. W., & Block, T. (2002). Use and reliability of the World Wide Web version of the block health habits and history questionnaire with older rural women. *Journal of Nutrition Education and Behavior*, 20–24.

https://doi.org/10.1016/S1499-4046(06)60307-2

Boutrolle, I., Arranz, D., Rogeaux, M., & Delarue, J. (2005). Comparing central location test and home use test results: Application of a new criterion. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2005.03.015

Boutrolle, I., Delarue, J., Arranz, D., Rogeaux, M., & Köster, E. P. (2007). Central location test vs. home use test: Contrasting results depending on product type. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2006.06.003

Bureau of Nutritional Sciences. (2012). *Guidance for the food industry on reducing sodium in processed foods, Canada*. *World action on salt*. Retrieved from http://www.worldactiononsalt.com/docs/world/78296.pdf

Busch, J. L. H. C., Yong, F. Y. S., & Goh, S. M. (2013). Sodium reduction: Optimizing product composition and structure towards increasing saltiness perception. *Trends in Food Science and Technology*, *29*(1), 21–34. https://doi.org/10.1016/j.tifs.2012.08.005

Cadena, R. S., Vidal, L., Ares, G., & Varela, P. (2014). Dynamic sensory descriptive methodologies. Time-intensity and temporal dominance of sensations. In P. Varela & G. Ares (Eds.), *Novel Techniques in Sensory Characterization and Consumer Profiling* (pp. 333–364). Boca Raton: CRC Press.

Cappuccio, F. P., Beer, M., & Strazzullo, P. (2019). Population dietary salt reduction and the risk of cardiovascular disease. A scientific statement from the European Salt Action Network. *Nutrition, Metabolism and Cardiovascular Diseases*, *29*(2), 107–114. https://doi.org/10.1016/j.numecd.2018.11.010

Castura, J. C. (2017). tempR: Temporal sensory data analysis. R package version 0.9.9.10. Retrieved from http://www.cran.r-project.org/package=tempR/

Castura, J. C. (2018). Dynamics of consumer perception. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 1: New approaches to classic methods* (Vol. 1, pp. 211–240). Elsevier Ltd. https://doi.org/https://doi.org/10.1016/B978-0-08-102089-0.00009-1

Castura, J. C., Antúnez, L., Giménez, A., & Ares, G. (2016). Temporal Check-All-That-Apply (TCATA): A novel dynamic method for characterizing products. *Food Quality and Preference*, *47*, 79–90. https://doi.org/10.1016/j.foodqual.2015.06.017

Chen, J. (2014). Food oral processing : Some important underpinning principles of eating and sensory perception. *Food Structure*, *1*(2), 91–105. https://doi.org/10.1016/j.foostr.2014.03.001

Cherdchu, P., & Chambers, E. (2014). Effect of carriers on descriptive sensory characteristics: A case study with soy sauce. *Journal of Sensory Studies*. https://doi.org/10.1111/joss.12100

Cho Long, L., Soh Min, L., & Kwang-Ok, K. (2015). Use of consumer acceptability as a tool to determine the level of sodium reduction: a case study on beef soup substituted with potassium chloride and soy-sauce odor. *Journal of Food Science*, *80*(11), S2570–S2577. https://doi.org/10.1111/1750-3841.13098

Cornelia, M., Triyanti, I., Prasetia, T., & Purnomo, C. (2016). Sensory evaluation and characterizations of emulsion containing sodium chloride and its application in corn soup. *Jurnal Teknologi Dan Industri Pangan*, *27*(2), 157–164. https://doi.org/10.6066/jtip.2016.27.2.157

Costa, R. G. B., Alves, R. C., Cruz, A. G. da, Sobral, D., Teodoro, V. A. M., Costa Junior, L. C. G., … Miguel, E. M. (2018). Manufacture of reduced-sodium Coalho cheese by partial replacement of NaCl with KCl. *International Dairy Journal*, *87*, 37–43. https://doi.org/10.1016/j.idairyj.2018.07.012

Czarnacka-Szymani, J., & Jezewska-Zychowicz, M. (2015). Impact of nutritional information on consumers' acceptance of cheese with reduced sodium chloride content. *International Dairy Journal*, *40*, 47–53. https://doi.org/10.1016/j.idairyj.2014.08.017

da Silva, T. L. T., de Souza, V. R., Pinheiro, A. C. M., Nunes, C. A., & Freire, T. V. M. (2014). Equivalence salting and temporal dominance of sensations analysis for different sodium chloride substitutes in cream cheese. *International Journal of Dairy Technology*, *67*(1), 31–38. https://doi.org/10.1111/1471-0307.12100

de Almeida, M. A., Montes, N., Saldaña, E., Pinto, J., Contreras-Castillo, C. J., Montes Villanueva, N. D., … Contreras-Castillo, C. J. (2017). Are sensory attributes and acceptance influenced by nutritional and health claims of low-sodium salami? Preliminary study with Brazilian consumers. *Scientia Agropecuaria*, *8*(4), 389–399. https://doi.org/10.17268/sci.agropecu.2017.04.10

de Andrade, J. C., Nalério, E. S., Giongo, C., de Barcellos, M. D., Ares, G. G., Deliza, R., … Deliza, R. (2018). Consumer sensory and hedonic perception of sheep meat coppa under blind and informed conditions. *Meat Science*, *137*(May 2017), 201–210. https://doi.org/10.1016/j.meatsci.2017.11.026

De Pelsmaeker, S., Schouteten, J. J., Lagast, S., Dewettinck, K., & Gellynck, X. (2017). Is taste the key driver for consumer preference? A conjoint analysis study. *Food Quality and Preference*, *62*, 323–331. https://doi.org/10.1016/j.foodqual.2017.02.018

de Souza, V. R., Freire, T. V. M., Saraiva, C. G., de Deus Souza Carneiro, J., Pinheiro, A. C. M., & Nunes, C. A. (2013). Salt equivalence and temporal dominance of sensations of different sodium chloride substitutes in butter. *Journal of Dairy Research*, *80*(3), 319–325. https://doi.org/10.1017/S0022029913000204

de Wijk, R. A., Engelen, L., Prinz, J. F., & Weenen, H. (2003). The influence of bite size and multiple bites on oral texture sensations. *Journal of Sensory Studies*, *18*(5), 423–435. https://doi.org/10.1111/j.1745-459X.2003.tb00398.x

Delgado-Pando, G., Fischer, E., Allen, P., Kerry, J. P., O'Sullivan, M. G., & Hamill, R. M. (2018). Salt content and minimum acceptable levels in whole-muscle cured meat products. *Meat Science*, *139*(January), 179–186. https://doi.org/10.1016/j.meatsci.2018.01.025

Dos Santos, B. A., Bastianello Campagnol, P. C., da Cruz, A. G., Galvão, M. T. E. L., Monteiro, R. A., Wagner, R., & Pollonio, M. A. R. (2015). Check all that apply and free listing to describe the sensory characteristics of low sodium dry fermented sausages: Comparison with trained panel. *Food Research International*, *76*(Part 3), 725–734. https://doi.org/10.1016/j.foodres.2015.06.035

Doyle, M. E., & Glass, K. A. (2010). Sodium reduction and its effect on food safety, food quality, and human health. *Comprehensive Reviews in Food Science and Food Safety*, *9*(1), 44–56. https://doi.org/10.1111/j.1541-4337.2009.00096.x

Drake, S. L., Lopetcharat, K., & Drake, M. A. (2011). Salty taste in dairy foods: Can we reduce the salt? *Journal of Dairy Science*, *94*(2), 636–645. https://doi.org/10.3168/jds.2010-3509

Durack, E., Alonso-Gomez, M., & Wilkinson, M. (2008). Salt: A review of its role in food science and public health. *Current Nutrition & Food Science*, *4*(4), 290–297.

https://doi.org/10.2174/157340108786263702

Esmerino, E. A., Castura, J. C., Ferraz, J. P., Tavares Filho, E. R., Silva, R., Cruz, A. G., … Bolini, H. M. A. (2017). Dynamic profiling of different ready-to-drink fermented dairy products: A comparative study using Temporal Check-All-That-Apply (TCATA), Temporal Dominance of Sensations (TDS) and Progressive Profile (PP). *Food Research International*, *101*(June), 249–258. https://doi.org/10.1016/j.foodres.2017.09.012

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2015). Impact of varying salt and fat levels on the physicochemical properties and sensory quality of white pudding. *Meat Science*, *103*, 75–82. https://doi.org/10.1016/j.meatsci.2014.12.010

Fellendorf, S., O'Sullivan, M. G., & Kerry, J. P. (2016). Effect of using ingredient replacers on the physicochemical properties and sensory quality of low-salt and low-fat white puddings. *European Food Research and Technology*, *242*(12), 2105–2118. https://doi.org/10.1007/s00217-016-2707-z ER

Fischer, P. W. F., Vigneault, M., Huang, R., Arvaniti, K., & Roach, P. (2009). Sodium food sources in the Canadian diet. *Applied Physiology, Nutrition, and Metabolism*, *34*(5), 884–892. https://doi.org/10.1139/H09-077

Fouladkhah, A., Berlin, D., & Bruntz, D. (2015). High-sodium processed foods: Public health burden and sodium reduction strategies for industry practitioners. *Food Reviews International*, *31*(4), 341–354. https://doi.org/10.1080/87559129.2015.1022829

Freire, T. V. M., Freire, D. O., de Souza, V. R., Gonçalves, C. S., Carneiro, J. de D. S., Nunes, C. A. A., … Marques Pinheiro, A. C. (2015). Salting potency and Time-Intensity profile of microparticulated sodium chloride in shoestring potatoes. *Journal of Sensory Studies*, *30*(1), 1–9. https://doi.org/10.1111/joss.12129

Galmarini, M. V., Loiseau, A.-L. L., Debreyer, D. D. D., Visalli, M., & Schlich, P. (2017). Use of multi-intake Temporal Dominance of Sensations (TDS) to evaluate the influence of wine on cheese perception. *Journal of Food Science*, *82*(11), 2669–2678. https://doi.org/10.1111/1750-3841.13932

Galmarini, M. V, Dufau, L., Loiseau, A. L., Visalli, M., & Schlich, P. (2018). Wine and cheese: two products or one association? A new method for assessing wine-cheese pairing.

Beverages, 2306-5710, *4*(1), 13. https://doi.org/10.3390/beverages4010013

Ganesan, B., Brown, K., Irish, D. A., Brothersen, C., & McMahon, D. J. (2014). Manufacture and sensory analysis of reduced- and low-sodium Cheddar and Mozzarella cheeses. *Journal of Dairy Science*, *97*(4), 1970–1982. https://doi.org/10.3168/jds.2013-7443

Gaudette, N. J., & Pietrasik, Z. (2017). The sensory impact of salt replacers and flavor enhancer in reduced sodium processed meats is matrix dependent. *Journal of Sensory Studies*, *32*(1), 1–11. https://doi.org/10.1111/joss.12247

Gonçalves, C., Rodrigues, J. J. J., Júnior, H., Carneiro, J. J., Freire, T., Freire, L. L. L., … Freire, L. L. L. (2017). Sodium reduction in margarine using NaCl substitutes. *Anais Da Academia Brasileira De Ciencias*, *89*(3), 2505–2513. https://doi.org/10.1590/0001-3765201720150618

Gotow, N., Omata, T., Uchida, M., Matsuzaki, N., Takata, S., Hagiwara, I., & Kobayakawa, T. (2018). Multi-sip Time-Intensity evaluation of retronasal aroma after swallowing Oolong tea beverage. *Foods*, *7*(11). https://doi.org/10.3390/foods7110177

Graudal, N. A., Hubeck-Graudal, T., & Jürgens, G. (2016). Reduced dietary sodium intake increases heart rate. A meta-analysis of 63 randomized controlled trials including 72 study populations. *Frontiers in Physiology*, *7*(MAR), 1–8. https://doi.org/10.3389/fphys.2016.00111

Graudal, N., & Jürgens, G. (2018). Conflicting evidence on health effects associated with salt reduction calls for a redesign of the salt dietary guidelines. *Progress in Cardiovascular Diseases*, *61*(1), 20–26. https://doi.org/10.1016/j.pcad.2018.04.008

Greiff, K., Mathiassen, J. R., Misimi, E., Hersleth, M., Aursand, I. G., Ekrem, M., … Aursand, I. G. (2015). Gradual reduction in sodium content in cooked ham, with corresponding change in sensorial properties measured by sensory evaluation and a multimodal Machine vision system. *PLoS ONE*, *10*(9), 1–15. https://doi.org/10.1371/journal.pone.0137805

Hayes, J. E., & Keast, R. S. J. (2011). Two decades of supertasting: Where do we stand? *Physiology and Behavior*, *104*(5), 1072–1074. https://doi.org/10.1016/j.physbeh.2011.08.003

Hayes, J. E., Sullivan, B. S., & Duffy, V. B. (2010). Explaining variability in sodium intake through oral sensory phenotype, salt sensation and liking. *Physiology and Behavior*, *100*(4), 369–380. https://doi.org/10.1016/j.physbeh.2010.03.017

Health Canada. (2017). *Front-of-Package nutrition labelling: September 18, 2017 Stakeholder engagement meeting*. Retrieved from https://www.canada.ca/en/services/health/publications/food-nutrition/labelling-stakeholder-engagement-meeting-september-2017.html

Health Canada. (2018a). Sodium intake of Canadians in 2017. Retrieved from https://www.canada.ca/en/health-canada/services/publications/food-nutrition/sodium-intake-canadians-2017.html

Health Canada. (2018b). *Sodium reduction in processed foods in Canada: An evaluation of progress toward voluntary targets from 2012 to 2016*. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/legislation-guidelines/guidance-documents/guidance-food-industry-reducing-sodium-processed-foods-progress-report-2017.html

Henrique, N. A., Deliza, R., & Rosenthal, A. (2015). Consumer Sensory Characterization of Cooked Ham Using the Check-All-That-Apply (CATA) Methodology. *Food Engineering Reviews*, *7*(2), 265–273. https://doi.org/10.1007/s12393-014-9094-7

Hooge, S., & Chambers, D. (2010). A comparison of basic taste modalities, using a descriptive analysis technique, for varying levels of sodium and KCL in two model soup systems. *Journal of Sensory Studies*, *25*(4), 521–535. https://doi.org/10.1111/j.1745-459X.2010.00284.x

Hoppu, U., Hopia, A., Pohjanheimo, T., Rotola-Pukkila, M., Makinen, S., Pihlanto, A., & Sandell, M. (2017). Effect of salt reduction on consumer acceptance and sensory quality of food. *Foods*, *6*(12). https://doi.org/10.3390/foods6120103

Hubbard, E. M., Jervis, S. M., & Drake, M. A. (2016). The effect of extrinsic attributes on liking of cottage cheese. *Journal of Dairy Science*. https://doi.org/10.3168/jds.2015-9547

Husson, F., Josse, J., Le, S., & Mazet, J. (2018). FactoMineR: Multivariate exploratory data analysis and data mining. R package. https://doi.org/10.1201/b10345-2

Husson, F., Le, S., & Cadoret, M. (2017). SensoMineR: Sensory data analysis. R package. https://doi.org/10.1111/j.1745-459X.2007.00137.x

Inguglia, E. S., Zhang, Z., Tiwari, B. K., Kerry, J. P., & Burgess, C. M. (2017). Salt reduction strategies in processed meat products – A review. *Trends in Food Science & Technology*, *59*, 70–78. https://doi.org/10.1016/j.tifs.2016.10.016

ISO. (2011). *ISO 3972: Sensory analysis - Methology - Method of investigating sensitivity of taste*. *INTERNATIONAL STANDARD ISO*.

Israr, T., Rakha, A., Sohail, M., Rashid, S., & Shehzad, A. (2016). Salt reduction in baked products: Strategies and constraints. *Trends in Food Science and Technology*, *51*, 98–105. https://doi.org/10.1016/j.tifs.2016.03.002

Jaeger, S. R. (2006). Non-sensory factors in sensory science research. *Food Quality and Preference*, *17*(1–2), 132–144. https://doi.org/10.1016/j.foodqual.2005.03.004

Jaeger, S. R., Alcaire, F., Hunter, D. C., Jin, D., Castura, J. C., & Ares, G. (2018). Number of terms to use in temporal check-all-that-apply studies (TCATA and TCATA Fading) for sensory product characterization by consumers. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2017.09.013

Jaenke, R., Barzi, F., McMahon, E., Webster, J., & Brimblecombe, J. (2017). Consumer acceptance of reformulated food products: A systematic review and meta-analysis of salt-reduced foods. *Critical Reviews in Food Science and Nutrition*, *57*(16), 3357–3372. https://doi.org/10.1080/10408398.2015.1118009

Jamieson, L., & Watling, E. (2017). Multiple-ingestion Time-Intensity. In *Time-dependent measures of perception in sensory evaluation* (pp. 321–342). Retrieved from %3CGo

Jinap, S., Hajeb, P., Karim, R., Norliana, S., & Abdul-Kadir, S. Y. R. (2016). Reduction of sodium content in spicy soups using monosodium glutamate. *Food and Nutrition Research*, *60*, 1–11. https://doi.org/10.3402/fnr.v60.30463

Kanter, R., Reyes, M., Swinburn, B., Vandevijvere, S., & Corvalán, C. (2019). The food supply prior to the implementation of the chilean law of food labeling and advertising. *Nutrients*, *11*(1), 1–10. https://doi.org/10.3390/nu11010052

Keast, R. S. J., & Breslin, P. A. S. (2003). An overview of binary taste-taste interactions. *Food Quality and Preference*, *14*(2), 111–124. https://doi.org/10.1016/S0950-3293(02)00110-6

Kloss, L., Meyer, J. D., Graeve, L., & Vetter, W. (2015). Sodium intake and its reduction by food reformulation in the European Union - A review. *NFS Journal*, *1*, 9–19. https://doi.org/10.1016/j.nfs.2015.03.001

Köster, E., & Mojet, J. (2018). Complexity of consumer perception. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 1: New approaches to classic methods* (Vol. 1, pp. 23–45). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102089-0.00002-9

Kremer, S., Mojet, J., & Shimojo, R. (2009). Salt reduction in foods using naturally brewed soy sauce. *Journal of Food Science*, *74*(6), S255–S262. https://doi.org/10.1111/j.1750-3841.2009.01232.x

Kremer, S., Shimojo, R., Holthuysen, N., Köster, E. P., & Mojet, J. (2013). Consumer acceptance of salt-reduced "soy sauce" foods over rapidly repeated exposure. *Food Quality and Preference*, *27*(2), 179–190. https://doi.org/10.1016/j.foodqual.2012.06.002

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software*. https://doi.org/10.18637/jss.v082.i13

La Croix, K. W., Fiala, S. C., Colonna, A. E., Durham, C. A., Morrissey, M. T., Drum, D. K., & Kohn, M. A. (2015). Consumer detection and acceptability of reduced-sodium bread. *Public Health Nutrition*, *18*(8), 1412–1418. https://doi.org/10.1017/S1368980014001748

Lahne, J. (2018). Evaluation of meals and food pairing. In G. Ares & P. Varela (Eds.), *Methods in consumer research, Volume 2: Alternative approaches and special applications* (1st ed., Vol. 2, pp. 85–107). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-101743-2.00004-2

Lawless, H. T., & Heymann, H. (2010). Physiological and psychological foundations of sensory function. In H. T. Lawless & H. Heymann (Eds.), *Sensory evaluation of food: principles and practices* (2nd ed., pp. 19–56). New York, NY: Springer New York. https://doi.org/10.1007/978-1-4615-7843-7_2

Lawless, H. T., Patel, A. A., & Lopez, N. V. (2016). Mixed messages: Ambiguous penalty information in modified restaurant menu items. *Food Quality and Preference*, *52*, 232–236. https://doi.org/10.1016/j.foodqual.2016.05.005

Lê, S., Josse, J., & Husson, F. (2008). FactoMineR : An R package for multivariate analysis.

Journal of Statistical Software, *25*(1), 253–258. https://doi.org/10.18637/jss.v025.i01

Lee III, W. E., & Pangborn, R. M. (1986). Time-intensity: The temporal aspects of sensory perception. *Food Technology, 40(11), 71-78. 82*. https://doi.org/10.1111/2041-210X.12508

Lee, S. H., Han, D. B., Caputo, V., & Nayga, R. M. (2015). Consumers' valuation for a reduced salt product: A nonhypothetical choice experiment. *Canadian Journal of Agricultural Economics*, *63*(4), 563–582. https://doi.org/10.1111/cjag.12081

Lenfant, F., Loret, C., Pineau, N., Hartmann, C., & Martin, N. (2009). Perception of oral food breakdown. The concept of sensory trajectory. *Appetite*, *52*(3), 659–667. https://doi.org/10.1016/j.appet.2009.03.003

Liem, D. G., Miremadi, F., & Keast, R. S. J. (2011). Reducing sodium in foods: The effect on flavor. *Nutrients*. https://doi.org/10.3390/nu3060694

Liem, D. G., Miremadi, F., Zandstra, E. H., & Keast, R. S. (2012). Health labelling can influence taste perception and use of table salt for reduced-sodium products. *Public Health Nutrition*, *15*(12), 2340–2347. https://doi.org/10.1017/s136898001200064x

Liem, D. G., Toraman Aydin, N., & Zandstra, E. H. (2012). Effects of health labels on expected and actual taste perception of soup. *Food Quality and Preference*, *25*(2), 192–197. https://doi.org/10.1016/j.foodqual.2012.02.015

Lima, A., Dufauret, M., le Révérend, B., Wooster, T. J., le Reverend, B., & Wooster, T. J. (2018). Deconstructing how the various components of emulsion creamers impact salt perception. *Food Hydrocolloids*, *79*, 310–318. https://doi.org/10.1016/j.foodhyd.2018.01.005

Lima, F. (2017). *Peru publishes warning manual for processed product food labels*. Retrieved from https://gain.fas.usda.gov/Recent GAIN Publications/Peru Publishes Warning Manual for Processed Product Food Labels_Lima_Peru_9-27-2017.pdf

Lioe, H., Apriyantono, A., Takara, K., Wada, K., & Yasuda, M. (2005). Umami taste enhancement of MSG/NaCl mixtures by subthreshold L-a-aromatic amino acids. *Journal of Food Science*, *70*, S401–S405.

Lopes, M., Cavaleiro, C., & Ramos, F. (2017). Sodium reduction in bread: A role for glasswort

(Salicornia ramosissima J. Woods). *Comprehensive Reviews in Food Science and Food Safety*, *16*(5), 1056–1071. https://doi.org/10.1111/1541-4337.12277

Lorido, L., Estévez, M., & Ventanas, S. (2018). Fast and dynamic descriptive techniques (Flash Profile, Time-intensity and Temporal Dominance of Sensations) for sensory characterization of dry-cured loins. *Meat Science*, *145*, 154–162. https://doi.org/10.1016/j.meatsci.2018.06.028

Lorido, L., Hort, J., Estevez, M., & Ventanas, S. (2016). Reporting the sensory properties of dry-cured ham using a new language: Time intensity (TI) and temporal dominance of sensations (TDS). *Meat Science*, *121*, 166–174. https://doi.org/10.1016/j.meatsci.2016.06.009

Lucas, L., Riddell, L., Liem, D. G., Whitelock, S., & Keast, R. (2011). The influence of sodium on liking and consumption of salty food. *Journal of Food Science*, *76*(1). https://doi.org/10.1111/j.1750-3841.2010.01939.x

Machín, L., Curutchet, M. R., Giménez, A., Aschemann-Witzel, J., & Ares, G. (2019). Do nutritional warnings do their work? Results from a choice experiment involving snack products. *Food Quality and Preference*, *77*(May), 159–165. https://doi.org/10.1016/j.foodqual.2019.05.012

McCaughey, S. (2007). Dietary salt and flavor: mechanisms of taste perception and physiological controls. In D. Kilcast & F. Angus (Eds.), *Reducing Salt in Foods* (pp. 77–98). Woodhead Publishing Limited. https://doi.org/10.1533/9781845693046.1.77

McGough, M. M., Sato, T., Rankin, S. A., & Sindelar, J. J. (2012). Reducing sodium levels in frankfurters using naturally brewed soy sauce. *Meat Science*, *91*(1), 69–78. https://doi.org/10.1016/j.meatsci.2011.12.008

McLean, R., Hoek, J., & Hedderley, D. (2012). Effects of alternative label formats on choice of high- and low-sodium products in a New Zealand population sample. *Public Health Nutrition*, *15*(5), 783–791. https://doi.org/10.1017/s1368980011003508

McLean, R. M. (2014). Measuring population sodium intake: A review of methods. *Nutrients*, *6*(11), 4651–4662. https://doi.org/10.3390/nu6114651

Meinert, L., Frøst, M. B., Bejerholm, C., & Aaslyng, M. D. (2011). Enhancing the sensory quality of vegetables by decreasing some less-desired sensory properties with low-fat pork gravy. *Journal of Culinary Science and Technology*, *9*(2), 113–131. https://doi.org/10.1080/15428052.2011.584496

Mente, A., O'Donnell, M., Rangarajan, S., McQueen, M., Dagenais, G., Wielgosz, A., … Yusuf, S. (2018). Urinary sodium excretion, blood pressure, cardiovascular disease, and mortality: a community-level prospective epidemiological cohort study. *The Lancet*, *392*(10146), 496–506. https://doi.org/10.1016/S0140-6736(18)31376-X

Meyners, M., Jaeger, S. R., & Ares, G. (2016). On the analysis of Rate-All-That-Apply (RATA) data. *Food Quality and Preference*, *49*, 1–10. https://doi.org/10.1016/j.foodqual.2015.11.003

Ministry of Health Israel. (2017). Food label and nutritional labeling. Retrieved June 28, 2019, from https://www.health.gov.il/English/Topics/FoodAndNutrition/Nutrition/Adequate_nutrition/Pages/labeling.aspx

Mitchell, M., Brunton, N. P., & Wilkinson, M. G. (2013). The influence of salt taste threshold on acceptability and purchase intent of reformulated reduced sodium vegetable soups. *Food Quality and Preference*, *28*(1), 356–360. https://doi.org/10.1016/j.foodqual.2012.11.002

Miyaki, T., Retiveau-Krogmann, A., Byrnes, E., & Takehana, S. (2016). Umami increases consumer ccceptability, and perception of sensory and emotional benefits without compromising health benefit perception. *Journal of Food Science*, *81*(2), S483–S493. https://doi.org/10.1111/1750-3841.13195

Monaco, R. di, Chengcheng, S., Masi, P., & Cavella, S. (2014). Temporal dominance of sensations: a review. *Trends in Food Science & Technology*, *38*(2), 104–112.

Monteiro, C. A., Cannon, G., Moubarac, J. C., Levy, R. B., Louzada, M. L. C., & Jaime, P. C. (2017). The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. *Public Health Nutrition*, *21*(01), 5–17. https://doi.org/10.1017/S1368980017000234

Newson, R. S., Elmadfa, I., Biro, G., Cheng, Y., Prakash, V., Rust, P., … Feunekes, G. I. J. (2013). Barriers for progress in salt reduction in the general population. An international study. *Appetite*, *71*, 22–31. https://doi.org/10.1016/j.appet.2013.07.003

Nguyen, Q. C., Næs, T., & Varela, P. (2018). When the choice of the temporal method does make a difference: TCATA, TDS and TDS by modality for characterizing semi-solid foods. *Food Quality and Preference*, *66*(December 2017), 95–106. https://doi.org/10.1016/j.foodqual.2018.01.002

Noort, M. W. J., Bult, J. H. F., & Stieger, M. (2012). Saltiness enhancement by taste contrast in bread prepared with encapsulated salt. *Journal of Cereal Science*, *55*(2), 218–225. https://doi.org/10.1016/j.jcs.2011.11.012

Parker, M. N., Lopetcharat, K., & Drake, M. A. (2018). Consumer acceptance of natural sweeteners in protein beverages. *Journal of Dairy Science*, *101*(10), 8875–8889. https://doi.org/10.3168/jds.2018-14707

Paulsen, M. T., Naes, T., Ueland, O., Rukke, E.-O., & Hersleth, M. (2013). Preference mapping of salmon-sauce combinations: The influence of temporal properties. *Food Quality and Preference*, *27*(2), 120–127. https://doi.org/10.1016/j.foodqual.2012.09.010

Paulsen, M. T., Nys, A., Kvarberg, R., & Hersleth, M. (2014). Effects of NaCl substitution on the sensory properties of sausages: Temporal aspects. *Meat Science*, *98*(2), 164–170. https://doi.org/10.1016/j.meatsci.2014.05.020

Paulsen, M. T., Ueland, Ø., Nilsen, A. N., Öström, Å., & Hersleth, M. (2012). Sensory perception of salmon and culinary sauces - An interdisciplinary approach. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2011.09.004

Pérez Rodrigo, C., Aranceta, J., Salvador, G., & Varela-Moreiras, G. (2015). Food Frequency Questionnaires. *Nutr Hosp*, *31*, 49–56. https://doi.org/10.3305/nh.2015.31.sup3.8751

Petersen, K. S., Rae, S., Venos, E., Malta, D., Trieu, K., Santos, J. A., … Arcand, J. A. (2019). Paucity of high-quality studies reporting on salt and health outcomes from the science of salt: A regularly updated systematic review of salt and health outcomes (April 2017 to March 2018). *Journal of Clinical Hypertension*, *21*(2), 307–323. https://doi.org/10.1111/jch.13450

Pietrasik, Z., & Gaudette, N. J. (2014). The impact of salt replacers and flavor enhancer on the processing characteristics and consumer acceptance of restructured cooked hams. *Meat Science*, *96*(3), 1165–1170. https://doi.org/10.1016/j.meatsci.2013.11.005

Pineau, N., de Bouillé, A. G., Lepage, M., Lenfant, F., Schlich, P., Martin, N., & Rytz, A. (2012). Temporal Dominance of Sensations: What is a good attribute list? *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2012.04.004

Pineau, N., Schlich, P., Cordelle, S., Mathonnière, C., Issanchou, S., Imbert, A., … Köster, E. (2009). Temporal Dominance of Sensations: Construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference*, *20*(6), 450–455. https://doi.org/10.1016/j.foodqual.2009.04.005

Ponce-Martínez, X., Colin-Ramirez, E., Sánchez-Puerto, P., Rivera-Mancía, S., Cartas-Rosado, R., Infante-Vázquez, O., … Vargas-Barrón, J. (2018). Bread consumption is associated with elevated blood pressure among adults living in Mexico city–A sub-analysis of the Tlalpan 2020 study. *Nutrients*, *10*(12), 1969. https://doi.org/10.3390/nu10121969

Powles, J., Fahimi, S., Micha, R., Khatibzadeh, S., Shi, P., Ezzati, M., … Mozaffarian, D. (2013). Global, regional and national sodium intakes in 1990 and 2010: a systematic analysis of 24 h urinary sodium excretion and dietary surveys worldwide. *BMJ Open*, *3*(12), e003733. https://doi.org/10.1136/bmjopen-2013-003733

Quilaqueo, M., Duizer, L., & Aguilera, J. M. (2015). The morphology of salt crystals affects the perception of saltiness. *Food Research International*, *76*, 675–681. https://doi.org/10.1016/j.foodres.2015.07.004

R Core Team. (2017). R: A language and environment for statistical computing. *R Foundation for Statistical Computing, Vienna, Austria*. Retrieved from https://www.r-project.org/

R Core Team. (2018). R: A language and environment for statistical computing. *R Foundation for Statistical Computing, Vienna, Austria*. Retrieved from https://www.r-project.org/

Rama, R., Chiu, N., Carvalho Da Silva, M., Hewson, L., Hort, J., & Fisk, I. D. (2013). Impact of salt crystal size on in-mouth delivery of sodium and saltiness perception from snack foods. *Journal of Texture Studies*, *44*(5), 338–345. https://doi.org/10.1111/jtxs.12017

Rios-Leyvraz, M., Bovet, P., Bochud, M., Genin, B., Russo, M., Rossier, M. F., … Chiolero, A. (2018). Estimation of salt intake and excretion in children in one region of Switzerland: a cross-sectional study. *European Journal of Nutrition*, *0*(0), 0. https://doi.org/10.1007/s00394-018-1845-4

Rodrigues, D. M., de Souza, V. R., Mendes, J. F., Nunes, C. A., & Pinheiro, A. C. M. (2016). Microparticulated salts mix: An alternative to reducing sodium in shoestring potatoes. *LWT - Food Science and Technology*, *69*, 390–399. https://doi.org/10.1016/j.lwt.2016.01.056

Rodrigues, J. F., Goncalves, C. S., Pereira, R. C., Carneiro, J. D. S., & Pinheiro, A. C. M. (2014). Utilization of temporal dominance of sensations and time intensity methodology for development of low-sodium Mozzarella cheese using a mixture of salts. *Journal of Dairy Science*, *97*(8), 4733–4744. https://doi.org/10.3168/jds.2014-7913

Rodrigues, J. F., Junqueira, G., Gonçalves, C. S., Carneiro, J. D. S., Pinheiro, A. C. M., & Nunes, C. A. (2014). Elaboration of garlic and salt spice with reduced sodium intake. *Anais Da Academia Brasileira de Ciencias*, *86*(4), 2065–2075. https://doi.org/10.1590/0001-3765201420130464

Rosett, T. R., Hamill, T., Morris, K., & Klein, B. P. (1997). Taste qualities of reduced-sodium soups as affected by serving temperature. *Journal of Food Science*, *62*(2), 421–424. https://doi.org/10.1111/j.1365-2621.1997.tb04017.x

Rosett, T. R., Kendregan, S. L., Gao, Y., Schmidt, S. J., & Klein, B. P. (1996). Thickening agents effects on sodium binding and other taste qualities of soup systems. *Journal of Food Science*, *61*(5), 1099–1104. https://doi.org/10.1111/j.1365-2621.1996.tb10939.x

Sandell, M., Hoppu, U., & Laaksonen, O. (2018). Consumer segmentation based on genetic variation in taste and smell. In *Methods in consumer research, Volume 1: New approaches to classic methods* (Vol. 1, pp. 423–447). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102089-0.00017-0

Schnettler, B., Ares, G., Sepúlveda, N., Bravo, S., Villalobos, B., Hueche, C., & Adasme-Berríos, C. (2019). How do consumers perceive reformulated foods after the implementation of nutritional warnings? Case study with frankfurters in Chile. *Food Quality and Preference*, *74*(December 2018), 179–188. https://doi.org/10.1016/j.foodqual.2019.01.021

Schnettler, B., Ares, G., Sepúlveda, N., Bravo, S., Villalobos, B., Hueche, C., & Lobos, G. (2019). Are consumers willing to pay more for reformulated processed meat products in the context of the implementation of nutritional warnings? Case study with frankfurters in Chile. *Meat Science*, *152*(February), 104–108. https://doi.org/10.1016/j.meatsci.2019.02.007

Shan, L. C., De Brún, A., Henchion, M., Li, C., Murrin, C., Wall, P. G., & Monahan, F. J. (2017). Consumer evaluations of processed meat products reformulated to be healthier – A conjoint analysis study. *Meat Science*, *131*, 82–89. https://doi.org/10.1016/j.meatsci.2017.04.239

Silow, C., Axel, C., Zannini, E., & Arendt, E. K. (2016). Current status of salt reduction in bread and bakery products – A review. *Journal of Cereal Science*, *72*, 135–145. https://doi.org/10.1016/j.jcs.2016.10.010

Silow, C., Zannini, E., Axel, C., Lynch, K. M., & Arendt, E. K. (2016). Effect of salt reduction on wheat-dough properties and quality characteristics of puff pastry with full and reduced fat content. *Food Research International*, *89*, 330–337. https://doi.org/10.1016/j.foodres.2016.08.031

Silva, H. L. A., Balthazar, C. F., Silva, R., Vieira, A. H., Costa, R. G. B., Esmerino, E. A., … Cruz, A. G. (2018). Sodium reduction and flavor enhancer addition in probiotic prato cheese: Contributions of quantitative descriptive analysis and temporal dominance of sensations for sensory profiling. *Journal of Dairy Science*, *101*(10), 8837–8846. https://doi.org/10.3168/jds.2018-14819

Sinopoli, D. A., & Lawless, H. T. (2012). Taste properties of potassium chloride alone and in mixtures with sodium chloride using a Check-All-That-Apply method. *Journal of Food Science*, *77*(9). https://doi.org/10.1111/j.1750-3841.2012.02862.x

Sodium Working Group Canada. (2010). *Sodium reduction strategy for Canada*. Retrieved from https://www.canada.ca/en/health-canada/services/food-nutrition/healthy-eating/sodium/related-information/reduction-strategy/recommendations-sodium-working-group.html

Soto-Escageda, J. A., Estañol-Vidal, B., Vidal-Victoria, C. A., Michel-Chávez, A., Sierra-Beltran, M. A., & Bourges-Rodríguez, H. (2016). Does salt addiction exist? *Salud Mental*, *39*(3), 175–181. https://doi.org/10.17711/SM.0185-3325.2016.016

Stieger, M. A., Bult, J. H. F., Hamer, R. J., & Noort, M. W. J. (2009). Food product with inhomogeneous tastant bulk distribution and method for making such food product. *The effects of brief mindfulness intervention on acute pain experience: An examination of individual difference*. https://doi.org/10.1017/CBO9781107415324.004

Stieger, M., & Van de Velde, F. (2013). Microstructure, texture and oral processing: New ways to reduce sugar and salt in foods. *Current Opinion in Colloid and Interface Science*, *18*(4), 334–348. https://doi.org/10.1016/j.cocis.2013.04.007

Sukkwai, S., Kijroongrojana, K., Chonpracha, P., Pujols, K. D., Alonso-Marenco, J. R., Ardoin, R., & Prinyawiwatkul, W. (2018). Effects of colorant concentration and ‘natural colour’ or ‘sodium content’ claim on saltiness perception, consumer liking and emotion, and purchase intent of dipping sauces. *International Journal of Food Science and Technology*, *53*(5), 1246–1254. https://doi.org/10.1111/ijfs.13704

Tórtora, G., Machín, L., & Ares, G. (2019). Influence of nutritional warnings and other label features on consumers’ choice: Results from an eye-tracking study. *Food Research International*, *119*(September 2018), 605–611. https://doi.org/10.1016/j.foodres.2018.10.038

Traynor, M. P., Burke, R., O’Sullivan, M. G., Hannon, J. A., & Barry-Ryan, C. (2013). Sensory and chemical interactions of food pairings (basmati rice, bacon and extra virgin olive oil) with banana. *Food Research International*, *54*(1), 569–577. https://doi.org/10.1016/j.foodres.2013.07.050

Trieu, K., McLean, R., Johnson, C., Santos, J. A., Angell, B., Arcand, J. A., … Webster, J. (2016). The science of salt: A regularly updated systematic review of the implementation of salt reduction interventions (June–October 2015). *Journal of Clinical Hypertension*, *18*(6), 487–494. https://doi.org/10.1111/jch.12806

Trieu, K., McMahon, E., Santos, J. A., Bauman, A., Jolly, K.-A., Bolam, B., & Webster, J. (2017). Review of behaviour change interventions to reduce population salt intake. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 17. https://doi.org/10.1186/s12966-017-0467-1

Trieu, K., Neal, B., Hawkes, C., Dunford, E., Campbell, N., Rodriguez-Fernandez, R., … Webster, J. (2015). Salt reduction initiatives around the world – A systematic review of progress towards the global target. *PLoS ONE*, *10*(7), 1–22. https://doi.org/10.1371/journal.pone.0130247

Tuorila, H., & Monteleone, E. (2009). Sensory food science in the changing society:

Opportunities, needs, and challenges. *Trends in Food Science and Technology*. https://doi.org/10.1016/j.tifs.2008.10.007

van Eck, A., Fogliano, V., Galindo-Cuspinera, V., Scholten, E., & Stieger, M. (2019). Adding condiments to foods: How does static and dynamic sensory perception change when bread and carrots are consumed with mayonnaise? *Food Quality and Preference*, *73*(November 2018), 154–170. https://doi.org/10.1016/j.foodqual.2018.11.013

van Eck, A., Hardeman, N., Karatza, N., Fogliano, V., Scholten, E., & Stieger, M. (2019). Oral processing behavior and dynamic sensory perception of composite foods: Toppings assist saliva in bolus formation. *Food Quality and Preference*, *71*(March 2018), 497–509. https://doi.org/10.1016/j.foodqual.2018.05.009

Varela, P., Antúnez, L., Carlehög, M., Alcaire, F., Castura, J. C., Berget, I., … Ares, G. (2018). What is dominance? An exploration of the concept in TDS tests with trained assessors and consumers. *Food Quality and Preference*, *64*. https://doi.org/10.1016/j.foodqual.2017.10.014

Vázquez, M. B., Curia, A., & Hough, G. (2009). Sensory descriptive analysis, sensory acceptability and expectation studies on biscuits with reduced added salt and increased fiber. *Journal of Sensory Studies*, *24*(4), 498–511. https://doi.org/10.1111/j.1745-459X.2009.00223.x

Ventanas, S., Puolanne, E., & Tuorila, H. (2010). Temporal changes of flavour and texture in cooked bologna type sausages as affected by fat and salt content. *Meat Science*, *85*(3), 410–419. https://doi.org/10.1016/j.meatsci.2010.02.009

Vidal, L., Ares, G., Hedderley, D. I., Meyners, M., & Jaeger, S. R. (2016). Comparison of rate-all-that-apply (RATA) and check-all-that-apply (CATA) questions across seven consumer studies. *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2016.12.013

Wall, B. (2010). PepsiCo develops "Designer Salt" to chip away at sodium intake - WSJ. *Wall Street Journal, Easten Edition*, 1–4. Retrieved from https://www.wsj.com/articles/SB10001424052748704534904575131602283791566

Webster, J., Trieu, K., Dunford, E., & Hawkes, C. (2014). Target salt 2025: A global overview of national programs to encourage the food industry to reduce salt in foods. *Nutrients*, *6*(8), 3274–3287. https://doi.org/10.3390/nu6083274

Wendin, K., Langton, M., Caous, L., & Hall, G. (2000). Dynamic analyses of sensory and microstructural properties of cream cheese. In *Food Chemistry* (Vol. 71, pp. 363–378). https://doi.org/10.1016/S0308-8146(00)00200-4

Willems, A. A., Van Hout, D. H. A., Zijlstra, N., & Zandstra, E. H. (2013). Effects of salt labelling and repeated in-home consumption on long-term liking of reduced-salt soups. *Public Health Nutrition*, *17*(5), 1130–1137. https://doi.org/10.1017/S1368980013001055

World Health Organization. (2006). *Reducing salt intake in populations*. *WHO*. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/43653/9789241595377_eng.pdf

World Health Organization. (2014). Guideline: sodium intake for adults and children. *Guideline: Sodium Intake for Adults and Children*, 1–46. Retrieved from http://www.who.int/nutrition/publications/guidelines/sodium_intake/en/

World Health Organization. (2016). *The SHAKE technical package for salt reduction*. Retrieved from http://www.who.int/dietphysicalactivity/publications/shake-salt-habit/en/

Xin Wei Goh, F., Itohiya, Y., Shimojo, R., Sato, T., Hasegawa, K., & Lai Peng, L. (2011). Using naturally brewed soy sauce to reduce salt in selected foods. *Journal of Sensory Studies*, *26*(6), 429–435.

Zandstra, E. H., De Graaf, C., Mela, D. J., & Van Staveren, W. A. (2000). Short- and long-term effects of changes in pleasantness on food intake. *Appetite*. https://doi.org/10.1006/appe.1999.0304

Zandstra, E. H., Lion, R. R., & Newson, R. S. (2016). Salt reduction: Moving from consumer awareness to action. *Food Quality and Preference*, *48*, 376–381. https://doi.org/10.1016/j.foodqual.2015.03.005

Zandstra, E. H., Willems, A. A., & Lion, R. (2018). Making salt-reduced products more appealing to consumers: impact of front-of-pack messages on liking and table salt use over time. *Public Health Nutrition*, *21*(15), 2762–2772. https://doi.org/10.1017/S1368980018001714

Zhao, L., Kirkmeyer, S. V., & Tepper, B. J. (2003). A paper screening test to assess genetic taste sensitivity to 6-n-propylthiouracil. *Physiology and Behavior*. https://doi.org/10.1016/S0031-9384(03)00057-X

Zorn, S., Alcaire, F., Vidal, L., Giménez, A., & Ares, G. (2014). Application of multiple-sip temporal dominance of sensations to the evaluation of sweeteners. *Food Quality and Preference*, *36*, 135–143. https://doi.org/10.1016/j.foodqual.2014.04.003

APPENDICES

Appendix 1. The influences of extrinsic product attributes on consumer sensory perception, preference and choice of sodium-reduced foods

Recently, an increasing number of studies have been performed to explore the influence of extrinsic product attributes on consumer preference of sodium-reduced foods; most evaluated the influence of food labelling, particularly Front-Of-Pack (FOP) labelling for sodium reduction, on consumer liking, purchase intention (PI), willingness to pay (WTP) and choice of sodium-reduced foods. Other authors have reported significant influences of brand (Ares et al., 2018; Hubbard, Jervis, & Drake, 2016; Lee, Han, Caputo, & Nayga, 2015; McLean, Hoek, & Hedderley, 2012; Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Adasme-Berríos, 2019; Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Lobos, 2019), price (Hubbard et al., 2016; Lee et al., 2015; Shan et al., 2017) and country of origin (domestic vs. imported) (Lee et al., 2015). The aim of this review is to discuss the influence of extrinsic product attributes on consumer sensory perception, preference and choice of sodium-reduced foods. A part of the review, the following sections discuss the research methodologies that incorporate extrinsic product attributes and the impact of FOP labelling, one of the public and stakeholders' initiatives for dietary sodium reduction (Health Canada, 2017), on the consumer sensory perception, preference and choice of sodium-reduced foods.

1. Research methodologies that incorporate extrinsic product attributes

Consumer behavior and food choice are influenced by many interacting factors (Köster & Mojet, 2018). Although sensory perception is a key driver of consumer preference (De Pelsmaeker, Schouteten, Lagast, Dewettinck, & Gellynck, 2017), other extrinsic product attributes, i.e. product information, brand, price and convenience (Jaeger, 2006), influence consumer preference and choice of sodium-reduced foods. Sensory quality and product information were concurrently evaluated in recent studies to examine the influence of product information on consumer sensory perception and liking of sodium-reduced foods, in which consumers evaluated control and labeled samples (Liem, Toraman Aydin, & Zandstra, 2012; Schouteten et al., 2015) and/or involved in different test conditions, including blind tasting, expectancy with information and informed tasting (Table A1). Liking and WTP responses do not measure the same information (Almli & Hersleth, 2013); it is necessary to assess other variables representative of consumer preference. PI, WTP and choice of sodium-reduced foods were assessed by rating scales in most relevant studies. The auction sale with the Becker, De Groot and Marschak (BMD) procedure (Becker, DeGroot, & Marschak, 1964) has been used to increase the involvement of consumers in measurement of WTP for sodium-reduced foods (Almli & Hersleth, 2013; Zakowska-Biemans, Sajdakowska, & Issanchou, 2016). Moreover, several studies performed conjoint analysis or actual choice experiments without food tasting to evaluate the influence of extrinsic product attributes, such as labelling, price and brand, on consumer preference and choice of sodium-reduced foods.

2. Influence of FOP labelling on consumer sensory perception, preference and choice of sodium-reduced foods

Although consumer perception may be affected by the product information, consumers spend limited time reading labels (i.e. an average of 17 min for total time of shopping for US consumers (Zick & Stevens, 2010)) and have a limited understanding of food labels (He et al., 2018). Food labelling influences industry practices to reduce sodium content of food products but does not reduce consumer sodium intake (Shangguan et al., 2019). Different types of FOP labelling have been introduced globally for sodium reduction in processed foods, including nutrition claims, health tick logos, traffic lights, star-based systems, facts up front panel and nutritional warnings (Kanter, Vanderlee, & Vandevijvere, 2018). The appropriate sodium content information on labelling enhanced the choice of sodium-reduced products (McLean et al., 2012). FOP labelling with nutrition claims, including nutrition content and health claims, are very useful for consumers to make decision when shopping under time pressure. The effectiveness of the FOP messages depended on health motivation and perceived healthfulness (Bialkova, Sasse, & Fenko, 2016). Health-oriented consumers accepted 'worse taste' (i.e. functional foods) for health benefits and tended to purchase products with health choice logos (Vyth, Steenhuis, Roodenburg, Brug, & Seidell, 2010; Vyth, Steenhuis, Vlot, et al., 2010). However, taste-oriented consumers may interpret nutrition claims as a warning sign of changed or worse flavor (Verbeke, 2006), hence their sensory perception and acceptance of sodium-reduced foods with nutrition information is negatively influenced (Czarnacka-Szymani & Jezewska-Zychowicz, 2015; Sajdakowska et al., 2019).

The influences of FOP labelling on consumer perception and preference for sodium-reduced foods are diverse across food products and types of FOP labelling. The use of nutrition claims, including sodium content claims with or without sensory, health or social messages, increased perceived saltiness of dipping sauce (Sukkwai et al., 2018), Gouda cheese (Schouteten et al., 2015) and chicken soup (Liem, Miremadi, Zandstra, & Keast, 2012), changed perceived sensory profiles of sheep meat coppa (de Andrade et al., 2018) and ham (Henrique, Deliza, & Rosenthal, 2015). Nutrition claims decreased perceived liking of dipping sauce (Sukkwai et al., 2018) and biscuits (Vázquez, Curia, & Hough, 2009) and chicken soup (Liem, Miremadi, et al., 2012), but had no influence on perceived liking reported by other studies. For some studies, although the perceived saltiness and/or liking did not change, the expected saltiness and/or liking decreased with the presence of nutrition claims (Liem, Toraman Aydin, et al., 2012; Schouteten et al., 2015; Zandstra, Willems, & Lion, 2018). An increase in expected liking was also observed in salami (de Almeida et al., 2017) and Kanabos sausage (Zakowska-Biemans et al., 2016). Expected liking may be an important influence of consumer product choice while shopping at food stores. The presence of sodium content claims increased PI and WTP of several products (Czarnacka-Szymani & Jezewska-Zychowicz, 2015; Lee et al., 2015; Shan et al., 2017; Zakowska-Biemans et al., 2016).

The content of messages influences consumer perception of a food product. Zandstra, Carvalho, & van Herpen (2017) observed more frequent selection of sodium-reduced foods with health than taste focused messages. Willems et al. (2013) framed claims positively, hence they did not observe a negative influence of claims on expected and perceived taste as observed by Liem, Toraman Aydin, et al. (2012). Schouteten et al. (2015) suggested that consumers associated health labeled cheese with more negative and less positive emotions compared to the control cheese, which thus may affect choice of sodium-reduced formulations.

Health tick logos are less likely to affect consumer perception than nutrition claims; no influence of the Heart Foundation Tick on expected and perceived liking, a decrease in expected saltiness compared to the sample without FOP labelling but a greater expected saltiness compared to the sodium content claim for chicken soup were observed (Liem, Miremadi, et al., 2012; Liem, Toraman Aydin, et al., 2012). The use of traffic lights, fact up front panels and nutritional warnings increased selection of sodium-reduced foods in relevant studies, using conjoint analysis and actual choice experiments without food tasting. Nutritional warnings, which highlight the high content of sodium and other nutrients associated with non-communicable diseases, have been recently implemented in Chile (Kanter, Reyes, Swinburn, Vandevijvere, & Corvalán, 2019), with planned implementation in several countries including Canada (Health Canada, 2017), Israel (Ministry of Health Israel, 2017) and Peru (Bean, 2017). Although there is strongly evidence in recent studies that nutritional warnings on high sodium products helped to increase selection of sodium-reduced products without warnings, there have been no reports in the literature of the influence of nutritional warnings on perceived sensory perception and liking of sodium-reduced foods.

Overall, information on the FOP labelling influences consumer perception, preference and choice of sodium-reduced foods. Although FOP labelling with nutrition claims for 'reduced sodium/salt' can help to encourage the food industry to reduce sodium content in food products and consumers to select healthier foods, especially for health-oriented consumers, it may negatively influence consumer perception and preference, then decrease consumer choice of sodium-reduced foods, particularly for taste-oriented consumers. FOP labelling with nutritional warnings, i.e. a 'high in' FOP label on high sodium products, is the most appropriate labelling tool to help the food industry to decrease sodium content in food products and increase the consumer selection of sodium-reduced foods. Further studies on the influence of nutritional warnings on consumer sensory perception and preference of regular and sodium-reduced foods are needed to confirm its effectiveness and encourage governments to implement this type of FOP labelling to reduce global dietary sodium intake.

Table A1. Studies on the influence of Front-Of-Package labelling for sodium reduction on consumer perception and choice of sodium-reduced foods.

FOP Labelling	Studies	Methods	Products	Outcome variables	Significant influences
Sodium content claims/ formulation information	de Andrade et al. (2018)	CLT[1]	Sheep meat coppa	CATA[5] sensory profile, Liking	Changes in sensory profiles
	Sukkwai et al. (2018)	CLT	Dipping sauces	JAR[6] saltiness, Liking	Decreases in percieved JAR saltiness and liking (not for different 'reduced sodium' statements)
	Zakowska-Biemans et al. (2016)	CLT, Auction sale	Kanabos sausage	Liking, WTP[7] (Reservation price)	Increases in expected liking and reservation price
	Czarnacka-Szymani & Jezewska-Zychowicz (2015)	CLT	Edam cheese	Liking, WTP	Increases in WTP
	Schouteten et al. (2015)	CLT	Gouda cheese	Saltiness, Liking, PI[8], RATA[9] sensory and emotion profile	Decreases in expected saltiness and liking, perceived saltiness
	Almli & Hersleth (2013)	CLT, Auction sale	Smoked salmon	Liking, WTP (Reservation price)	No effects
	Liem, Toraman Aydin, et al. (2012)	CLT	Chicken soup	Saltiness, Liking	A decrease in expected saltiness
	Vázquez et al. (2009)	CLT	Biscuits	Liking	Decreases in expected and perceived liking
	Resconi et al. (2016)	CBC[2]	Cooked ham	Hypothetical choice	Sodium reduction information was less important than exclusion of phosphates,

					appearance, but higher than price and fibre label
	Shan et al. (2017)	RBC[3]	Ham, sausages, beef burger	PI	An increase in PI, less important than price
	Lee et al. (2015)	CBC, Actual choice experiment	Canned ham	Preference, WTP, Choice	Higher price
Sodium content claims and sensory /health/social messages	Zandstra et al. (2018)	CLT, Repeated consumptions	Chicken noodle soup	Attribute intensity, Liking, PI, Hypothetical choice	Less expected-liking for the social message than sensory message; the effect of interest in salt reduction on liking
	de Almeida et al. (2017)	CLT	Salami	JAR sensory attributes, Liking	An increase in expected liking
	Zandstra et al. (2017)	Virtual shelf, CLT	Tomato soup	- Hypothetical choice, PI - Saltiness, Liking	An increase in choice for health than taste focused messsages; An increase expected saltiness for desciptive norm messages
	Henrique et al. (2015)	CLT	Ham	CATA sensory profile, Liking, WTP	Changes in sensory profiles
	Willems et al. (2013)	CLT, HUT, Repeated consumptions	Chicken noodle soup	Liking	No effects
	Liem, Miremadi, et al. (2012)	CLT	Chicken soup	JAR saltiness, Liking	Decreases in expected and perceived JAR saltiness and liking
Health logos	Liem, Toraman Aydin, et al. (2012)	CLT	Chicken soup	Saltiness, Liking	Greater expected saltiness than the sodium content claim
	Liem, Miremadi, et al. (2012)	CLT	Chicken soup	JAR saltiness, Liking	A decrease in expected JAR saltiness
Traffic lights	McLean et al. (2012)	CBC	Canned baked beans		An increase in choice
Facts up front panel	Tórtora, Machín, & Ares (2019)	CBC, Eye-tracking	Cookies and crackers	Hypothetical choice	An increase in choice; more important than claims of free cholesterol and trans fat
Nutritional warnings	Machín, Curutchet, Giménez, Aschemann-Witzel, & Ares (2019)	Actual choice experiment, Eye-traking	Snack foods	Choice	An increase in choice
	Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Adasme-Berríos (2019) Schnettler, Ares, Sepúlveda, Bravo, Villalobos, Hueche, & Lobos (2019)	RBC	Frankfurter	PI	An increase in PI; more important than brand
	Tórtora et al. (2019)	CBC, Eye-tracking	Cookies and crackers	Hypothetical choice	An increase in choice; nutritional warnings were more efficient than facts up front panel, FOP labelling was less important than product type and more important than claims of free cholesterol and trans fat
	Ares et al. (2018)	CBC	Bread	Hypothetical choice	An increase in choice; nutritional warnings tended to be more important than brand

1: Central location test (CLT)
2: Choice-based conjoint analysis (CBC)
3: Rating-based conjoint analysis (RBC)
4: Home use test (HUT)
5: Check-All-That-Apply (CATA)
6: Just-About-Right (JAR) scale
7: Willingness-to-pay (WTP)
8: Purchase intention (PI)
9: Rate-All-That-Apply (RATA) scale

3. References

Almli, V. L., & Hersleth, M. (2013). Salt replacement and injection salting in smoked salmon evaluated from descriptive and hedonic sensory perspectives. *Aquaculture International*, *21*(5), 1091–1108. https://doi.org/10.1007/s10499-012-9615-4

Ares, G., Aschemann-Witzel, J., Curutchet, M. R., Antúnez, L., Machín, L., Vidal, L., & Giménez, A. (2018). Product reformulation in the context of nutritional warning labels: Exploration of consumer preferences towards food concepts in three food categories. *Food Research International*, *107*, 669–674. https://doi.org/10.1016/j.foodres.2018.03.021

Bean, C. E. (2017). *Peru Publishes Warning Manual for Processed Product Food Labels*. Retrieved from https://gain.fas.usda.gov/Recent GAIN Publications/Peru Publishes Warning Manual for Processed Product Food Labels_Lima_Peru_9-27-2017.pdf

Becker, G. M., DeGroot, M. H., & Marschak, J. (1964). Measuring utility by a single-response sequential method. *Behavioral Science*. https://doi.org/10.1002/bs.3830090304

Bialkova, S., Sasse, L., & Fenko, A. (2016). The role of nutrition labels and advertising claims in altering consumers' evaluation and choice. *Appetite*, *96*, 38–46. https://doi.org/10.1016/j.appet.2015.08.030

Czarnacka-Szymani, J., & Jezewska-Zychowicz, M. (2015). Impact of nutritional information on consumers' acceptance of cheese with reduced sodium chloride content. *International Dairy Journal*, *40*, 47–53. https://doi.org/10.1016/j.idairyj.2014.08.017

de Almeida, M. A., Montes, N., Saldaña, E., Pinto, J., Contreras-Castillo, C. J., Montes Villanueva, N. D., … Contreras-Castillo, C. J. (2017). Are sensory attributes and acceptance influenced by nutritional and health claims of low-sodium salami? Preliminary study with Brazilian consumers. *Scientia Agropecuaria*, *8*(4), 389–399. https://doi.org/10.17268/sci.agropecu.2017.04.10

de Andrade, J. C., Nalério, E. S., Giongo, C., de Barcellos, M. D., Ares, G. G., Deliza, R., … Deliza, R. (2018). Consumer sensory and hedonic perception of sheep meat coppa under blind and informed conditions. *Meat Science*, *137*(May 2017), 201–210. https://doi.org/10.1016/j.meatsci.2017.11.026

De Pelsmaeker, S., Schouteten, J. J., Lagast, S., Dewettinck, K., & Gellynck, X. (2017). Is taste the key driver for consumer preference? A conjoint analysis study. *Food Quality and Preference*, *62*, 323–331. https://doi.org/10.1016/j.foodqual.2017.02.018

He, Y., Huang, L., Yan, S., Li, Y., Lu, L., Wang, H., … Zhang, P. (2018). Awareness, understanding and use of sodium information labelled on pre-packaged food in Beijing:a cross-sectional study. *BMC Public Health*, *18*(1), 1–9. https://doi.org/10.1186/s12889-018-5396-7

Health Canada. (2017). *Front-of-Package Nutrition Labelling: September 18, 2017 Stakeholder Engagement Meeting*. Retrieved from https://www.canada.ca/en/services/health/publications/food-nutrition/labelling-stakeholder-engagement-meeting-september-2017.html

Henrique, N. A., Deliza, R., & Rosenthal, A. (2015). Consumer Sensory Characterization of Cooked Ham Using the Check-All-That-Apply (CATA) Methodology. *Food Engineering Reviews*, *7*(2), 265–273. https://doi.org/10.1007/s12393-014-9094-7

Hubbard, E. M., Jervis, S. M., & Drake, M. A. (2016). The effect of extrinsic attributes on liking of cottage cheese. *Journal of Dairy Science*. https://doi.org/10.3168/jds.2015-9547

Jaeger, S. R. (2006). Non-sensory factors in sensory science research. *Food Quality and Preference*, *17*(1–2), 132–144. https://doi.org/10.1016/j.foodqual.2005.03.004

Kanter, R., Reyes, M., Swinburn, B., Vandevijvere, S., & Corvalán, C. (2019). The food supply prior to the implementation of the chilean law of food labeling and advertising. *Nutrients*, *11*(1), 1–10. https://doi.org/10.3390/nu11010052

Kanter, R., Vanderlee, L., & Vandevijvere, S. (2018). Front-of-package nutrition labelling policy: global progress and future directions. *Public Health Nutrition*, *21*(8), 1399–1408. https://doi.org/10.1017/S1368980018000010

Köster, E., & Mojet, J. (2018). *Complexity of Consumer Perception*. *Methods in Consumer Research, Volume 1* (Vol. 1). Elsevier Ltd. https://doi.org/10.1016/B978-0-08-102089-0.00002-9

Lee, S. H., Han, D. B., Caputo, V., & Nayga, R. M. (2015). Consumers' Valuation for a Reduced Salt Product: A Nonhypothetical Choice Experiment. *Canadian Journal of Agricultural Economics*, *63*(4), 563–582. https://doi.org/10.1111/cjag.12081

Liem, D. G., Miremadi, F., Zandstra, E. H., & Keast, R. S. (2012). Health labelling can influence taste perception and use of table salt for reduced-sodium products. *Public Health Nutrition*, *15*(12), 2340–2347. https://doi.org/10.1017/s136898001200064x

Liem, D. G., Toraman Aydin, N., & Zandstra, E. H. (2012). Effects of health labels on expected and actual taste perception of soup. *Food Quality and Preference*, *25*(2), 192–197. https://doi.org/10.1016/j.foodqual.2012.02.015

Machín, L., Curutchet, M. R., Giménez, A., Aschemann-Witzel, J., & Ares, G. (2019). Do nutritional warnings do their work? Results from a choice experiment involving snack products. *Food Quality and Preference*, *77*(May), 159–165. https://doi.org/10.1016/j.foodqual.2019.05.012

McLean, R., Hoek, J., & Hedderley, D. (2012). Effects of alternative label formats on choice of high- and low-sodium products in a New Zealand population sample. *Public Health Nutrition*, *15*(5), 783–791. https://doi.org/10.1017/s1368980011003508

Ministry of Health Israel. (2017). Food Label and Nutritional Labeling. Retrieved June 28, 2019, from https://www.health.gov.il/English/Topics/FoodAndNutrition/Nutrition/Adequate_nutrition/Pages/labeling.aspx

Resconi, V. C., Keenan, D. F., Barahona, M., Guerrero, L., Kerry, J. P., & Hamill, R. M. (2016). Rice starch and fructo-oligosaccharides as substitutes for phosphate and dextrose in whole muscle cooked hams: Sensory analysis and consumer preferences. *LWT - Food Science and Technology*, *66*, 284–292. https://doi.org/10.1016/j.lwt.2015.10.048

Sajdakowska, M., Gebski, J., Zakowska-Biemans, S., Jezewska-Zychowicz, M., Gębski, J., Żakowska-Biemans, S., & Jeżewska-Zychowicz, M. (2019). Willingness to eat bread with health benefits: habits, taste and health in bread choice. *Public Health*, *167*, 78–87. https://doi.org/10.1016/j.puhe.2018.10.018

Schnettler, B., Ares, G., Sepúlveda, N., Bravo, S., Villalobos, B., Hueche, C., & Adasme-Berríos, C. (2019). How do consumers perceive reformulated foods after the implementation of nutritional warnings? Case study with frankfurters in Chile. *Food Quality and Preference*, *74*(December 2018), 179–188. https://doi.org/10.1016/j.foodqual.2019.01.021

Schnettler, B., Ares, G., Sepúlveda, N., Bravo, S., Villalobos, B., Hueche, C., & Lobos, G. (2019). Are consumers willing to pay more for reformulated processed meat products in the context of the implementation of nutritional warnings? Case study with frankfurters in Chile. *Meat Science*, *152*(February), 104–108. https://doi.org/10.1016/j.meatsci.2019.02.007

Schouteten, J. J., De Steur, H., De Pelsmaeker, S., Lagast, S., De Bourdeaudhuij, I., & Gellynck, X. (2015). Impact of Health Labels on Flavor Perception and Emotional Profiling: A Consumer Study on Cheese. *Nutrients*, *7*(12), 10251–10268. https://doi.org/10.3390/nu7125533

Shan, L. C., De Brún, A., Henchion, M., Li, C., Murrin, C., Wall, P. G., & Monahan, F. J. (2017). Consumer evaluations of processed meat products reformulated to be healthier – A conjoint analysis study. *Meat Science*, *131*, 82–89. https://doi.org/10.1016/j.meatsci.2017.04.239

Shangguan, S., Afshin, A., Shulkin, M., Ma, W., Marsden, D., Smith, J., … Mozaffarian, D. (2019). A Meta-Analysis of Food Labeling Effects on Consumer Diet Behaviors and Industry Practices. *American Journal of Preventive Medicine*. Elsevier Inc. https://doi.org/10.1016/j.amepre.2018.09.024

Sukkwai, S., Kijroongrojana, K., Chonpracha, P., Pujols, K. D., Alonso-Marenco, J. R., Ardoin, R., & Prinyawiwatkul, W. (2018). Effects of colorant concentration and 'natural colour' or 'sodium content' claim on saltiness perception, consumer liking and emotion, and purchase intent of dipping sauces. *International Journal of Food Science and Technology*, *53*(5), 1246–1254. https://doi.org/10.1111/ijfs.13704

Tórtora, G., Machín, L., & Ares, G. (2019). Influence of nutritional warnings and other label features on consumers' choice: Results from an eye-tracking study. *Food Research International*, *119*(September 2018), 605–611. https://doi.org/10.1016/j.foodres.2018.10.038

Vázquez, M. B., Curia, A., & Hough, G. (2009). Sensory descriptive analysis, sensory acceptability and expectation studies on biscuits with reduced added salt and increased fiber. *Journal of Sensory Studies*, *24*(4), 498–511. https://doi.org/10.1111/j.1745-459X.2009.00223.x

Verbeke, W. (2006). Functional foods: Consumer willingness to compromise on taste for health? *Food Quality and Preference*. https://doi.org/10.1016/j.foodqual.2005.03.003

Vyth, E. L., Steenhuis, I. H. M., Roodenburg, A. J. C., Brug, J., & Seidell, J. C. (2010). Front-of-pack nutrition label stimulates healthier product development: a quantitative analysis.

International Journal of Behavioral Nutrition and Physical Activity, *7*. https://doi.org/10.1186/1479-5868-7-65

Vyth, E. L., Steenhuis, I. H. M., Vlot, J. A., Wulp, A., Hogenes, M. G., Looije, D. H., … Seidell, J. C. (2010). Actual use of a front-of-pack nutrition logo in the supermarket: Consumers motives in food choice. *Public Health Nutrition*. https://doi.org/10.1017/S1368980010000637

Willems, A. A., Van Hout, D. H. A., Zijlstra, N., & Zandstra, E. H. (2013). Effects of salt labelling and repeated in-home consumption on long-term liking of reduced-salt soups. *Public Health Nutrition*, *17*(5), 1130–1137. https://doi.org/10.1017/S1368980013001055

Zakowska-Biemans, S., Sajdakowska, M., & Issanchou, S. (2016). Impact of Innovation on Consumers Liking and Willingness to Pay for Traditional Sausages. *Polish Journal of Food and Nutrition Sciences*, *66*(2), 119–127. https://doi.org/10.1515/pjfns-2016-0004

Zandstra, E. H., Carvalho, Á. H. P., & van Herpen, E. (2017). Effects of front-of-pack social norm messages on food choice and liking. *Food Quality and Preference*, *58*, 85–93. https://doi.org/10.1016/j.foodqual.2017.01.007

Zandstra, E. H., Willems, A. A., & Lion, R. (2018). Making salt-reduced products more appealing to consumers: impact of front-of-pack messages on liking and table salt use over time. *Public Health Nutrition*, *21*(15), 2762–2772. https://doi.org/10.1017/S1368980018001714

Zick, C. D., & Stevens, R. B. (2010). Trends in Americans food-related time use: 1975-2006. *Public Health Nutrition*. https://doi.org/10.1017/S1368980009992138

Appendix 2. Supplemental figures of Chapter 3

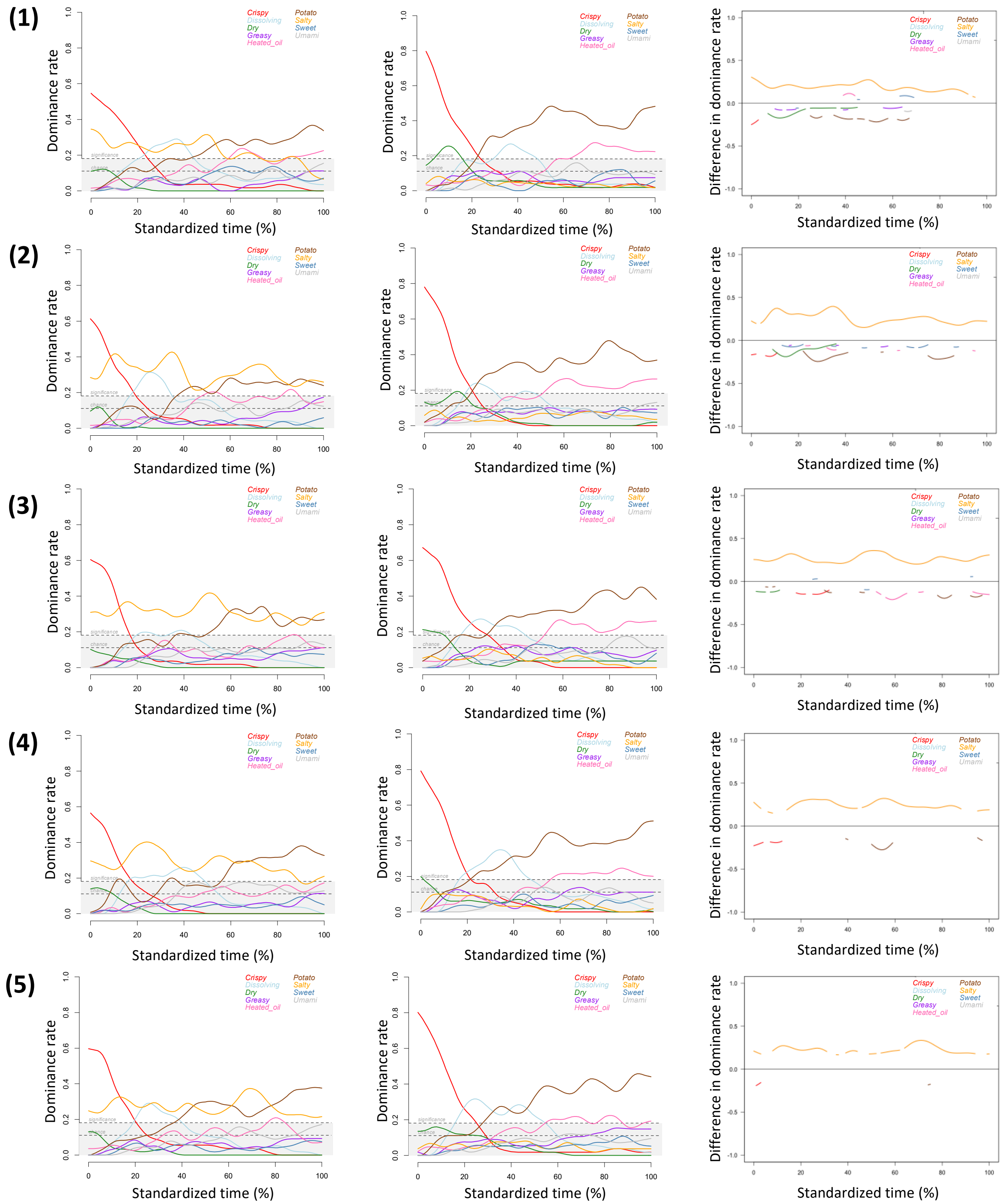


Figure A1. TDS profiles for regular (left) and sodium-reduced (middle) chips, and significant difference curves (right) of multiple intakes: bite 1 (1), bite 2 (2), bite 3 (3), bite 4 (4) and bite 5 (5) (n=54).

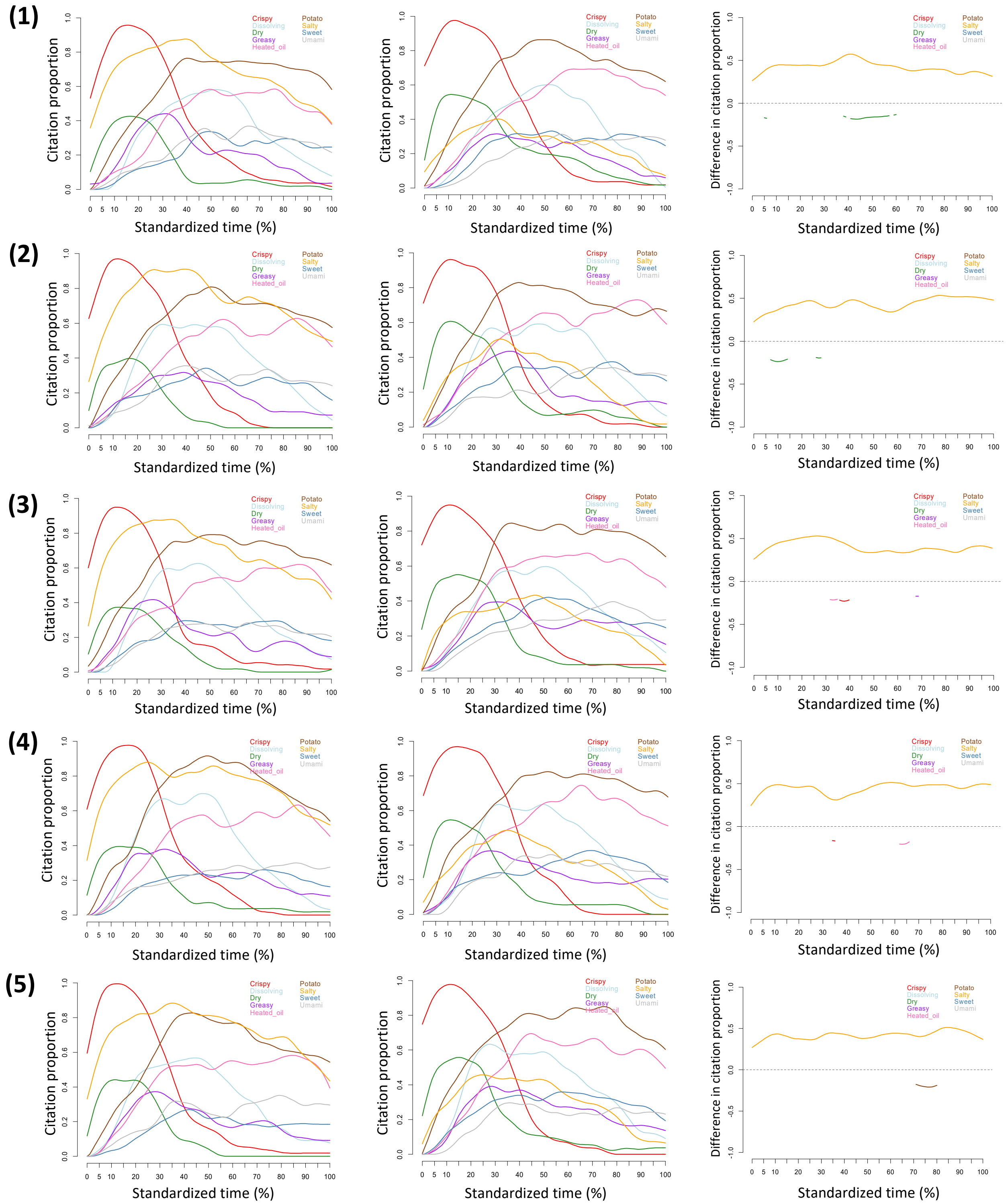


Figure A2. TCATA profiles for regular (left) and sodium-reduced (middle) chips, and significant difference curves (right) of multiple intakes: bite 1 (1), bite 2 (2), bite 3 (3), bite 4 (4) and bite 5 (5) (n=54).

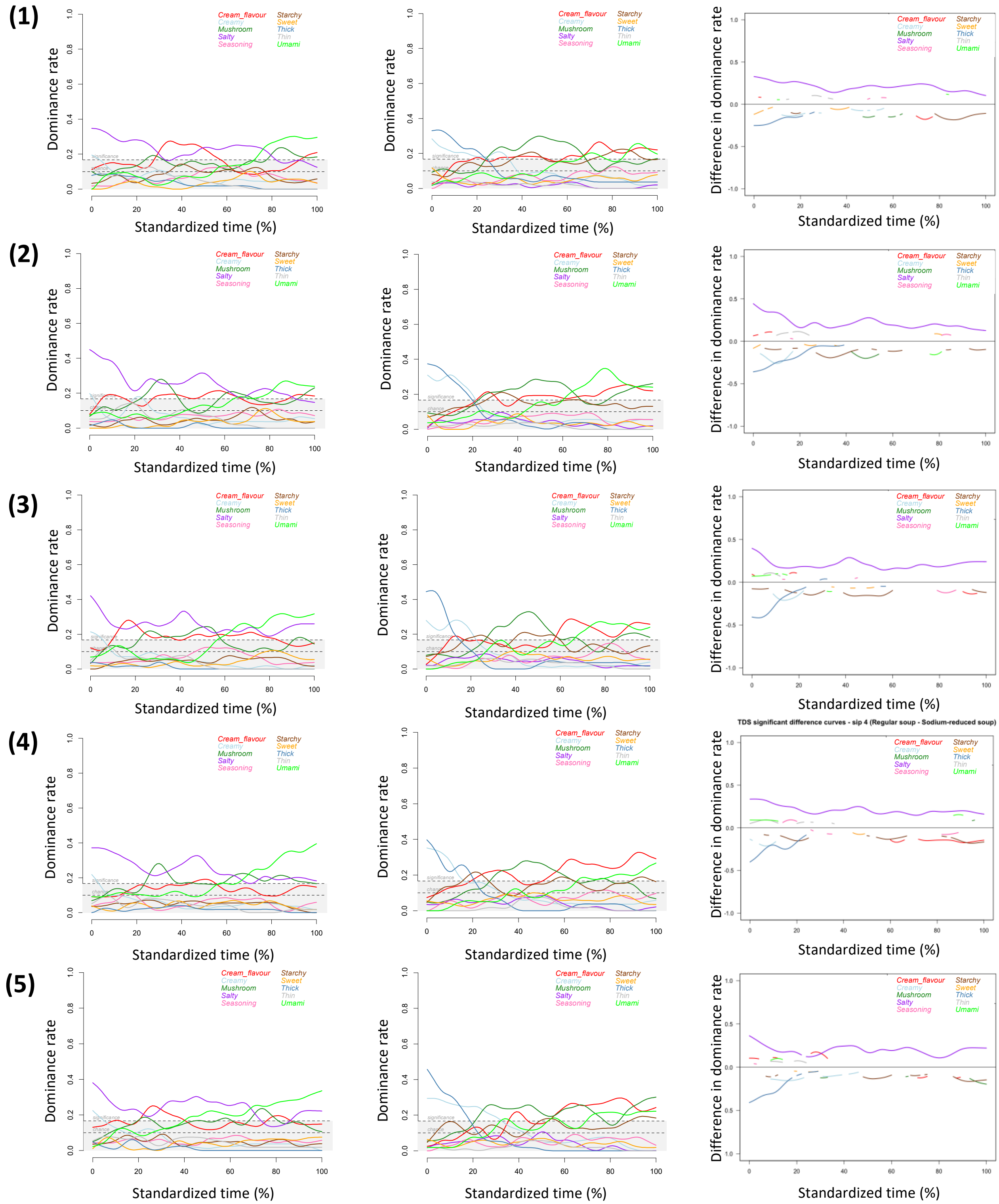


Figure A3. TDS profiles for regular (left) and sodium-reduced (middle) soup, and significant difference curves (right) of multiple intakes: sip 1 (1), sip 2 (2), sip 3 (3), sip 4 (4) and sip 5 (5) (n=54).

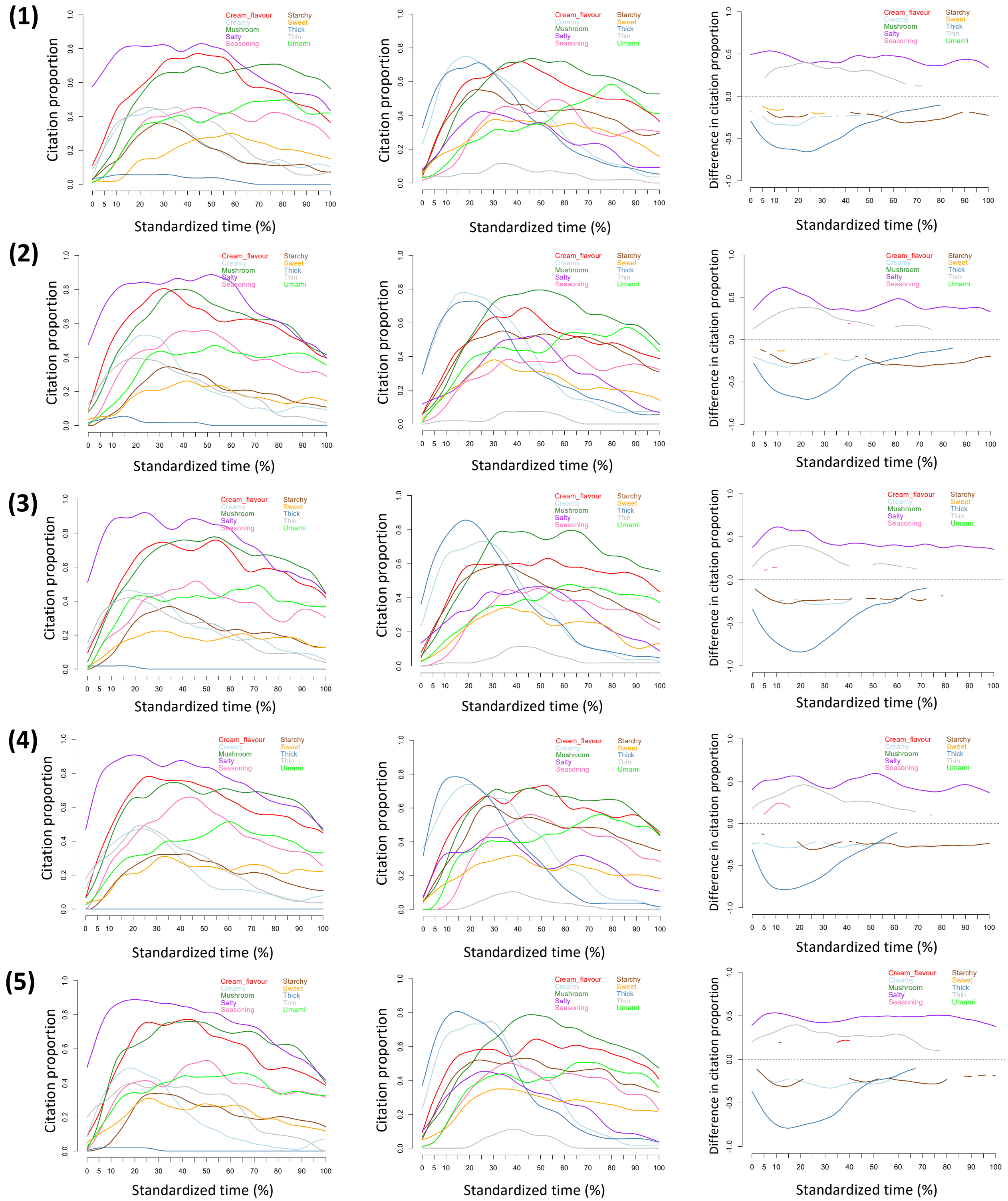


Figure A4. TCATA profiles for regular (left) and sodium-reduced (middle) soup, and significant difference curves (right) of multiple intakes: sip 1 (1), sip 2 (2), sip 3 (3), sip 4 (4) and sip 5 (5) (n=54).

Appendix 3. Supplemental results of Chapter 4

R outputs for description of consumer clusters by categorical variables (age, gender, consumption frequency of study products) and sensory attribute perception in 3 consumer panels for evaluation of 3 product pairs, as following.

1. Evaluation of salsa and corn chips

There are 3 clusters (n1=12, n2=41, n3=44); one participant was treated as supplemental individual (outlier).

```
Link between the cluster variable and the categorical variables (chi-square test)
=================================================================================
              p.value df
Chips_Salsa.F 0.01559007  6

Description of each cluster by the categories
=============================================
$`1`
                  Cla/Mod Mod/Cla   Global    p.value    v.test
Salsa.F=2-3 per month       0       0 23.71134 0.03078326 -2.159863

$`2`
                 Cla/Mod Mod/Cla   Global     p.value    v.test
Chips.F=>=3 per week       0       0 8.247423 0.009829034 -2.581787

$`3`
                        Cla/Mod  Mod/Cla    Global     p.value    v.test
Chips_Salsa.F=1-2 per week  80.00000 27.27273 15.463918 0.004199136  2.862801
Chips.F=>=3 per week        87.50000 15.90909  8.247423 0.016506033  2.397530
Chips_Salsa.F=<=1 per month 36.36364 45.45455 56.701031 0.045700420 -1.998150


Link between the cluster variable and the quantitative variables
================================================================
                      Eta2      P-value
Salsa              0.67234195 1.677951e-23
Reduced_chips_Salsa 0.56854936 6.946443e-18
Reg_chips_Salsa     0.55228864 3.952859e-17
Reduced_chips       0.23999832 2.501980e-06
Reg_chips           0.12910302 1.508130e-03
Crunchiness.2       0.12531902 1.848992e-03
Crunchiness         0.12451746 1.930332e-03
Crunchiness.4       0.08305332 1.698916e-02
Salty.2             0.07609720 2.423457e-02
Salty.1             0.06403447 4.458751e-02

Description of each cluster by quantitative variables
=====================================================
$`1`
                   v.test Mean in category Overall mean sd in category Overall sd      p.value
Graininess.2        2.042674         2.083333    1.6082474      0.6400955  0.8562289 4.108472e-02
Spice.1            -1.968310         0.000000    0.2989691      0.0000000  0.5591774 4.903241e-02
Salty.2            -2.144454         0.750000    1.1134021      0.7216878  0.6238604 3.199653e-02
Crunchiness        -2.553003         0.000000    0.4329897      0.0000000  0.6243713 1.067984e-02
Reduced_chips_Salsa -4.949154        5.416667    7.2061856      1.6562172  1.3311350 7.453683e-07
Reg_chips_Salsa    -5.413432         4.916667    7.1237113      1.6562172  1.5009120 6.182811e-08
Salsa              -7.581030         3.666667    6.7216495      1.0274023  1.4835335 3.428228e-14

$`2`
                   v.test Mean in category Overall mean sd in category Overall sd      p.value
Crunchiness         3.028499        0.6585366    0.4329897      0.7194088  0.6243713 2.457718e-03
Salty.4            -2.043984        1.2682927    1.4536082      0.7658692  0.7600952 4.095515e-02
Crunchiness.1      -2.403161        2.2439024    2.4123711      0.6160649  0.5877193 1.625405e-02
Crunchiness.4      -2.788133        1.9512195    2.1752577      0.6227876  0.6736622 5.301282e-03
Reg_chips_Salsa    -2.870804        6.6097561    7.1237113      1.0091786  1.5009120 4.094287e-03
Crunchiness.2      -3.409561        2.1463415    2.4123711      0.6462264  0.6541316 6.506754e-04
```

	v.test	Mean in category	Overall mean	sd in category	Overall sd	p.value
Reg_chips	-3.456965	6.8048780	7.2061856	1.1309291	0.9732308	5.462960e-04
Reduced_chips_Salsa	-3.602776	6.6341463	7.2061856	0.7572768	1.3311350	3.148372e-04
Reduced_chips	-4.373874	6.4634146	7.0618557	1.1282960	1.1470665	1.220606e-05

$`3`

	v.test	Mean in category	Overall mean	sd in category	Overall sd	p.value
Reduced_chips_Salsa	6.848015	8.227273	7.206186	0.6347382	1.3311350	7.488159e-12
Reg_chips_Salsa	6.428769	8.204545	7.123711	0.7254950	1.5009120	1.286412e-10
Salsa	5.094132	7.568182	6.721649	0.8892726	1.4835335	3.503419e-07
Reduced_chips	4.648158	7.659091	7.061856	0.8775788	1.1470665	3.349128e-06
Reg_chips	3.112091	7.545455	7.206186	0.7215685	0.9732308	1.857671e-03
Crunchiness.2	3.056978	2.636364	2.412371	0.5677271	0.6541316	2.235805e-03
Salty.1	2.442749	1.977273	1.762887	0.7534357	0.7835052	1.457587e-02
Salty.2	2.279928	1.272727	1.113402	0.5378254	0.6238604	2.261197e-02
Crunchiness.1	2.021520	2.545455	2.412371	0.5416534	0.5877193	4.322599e-02

2. Evaluation of ketchup and tater tots

There are 3 clusters (n1=29, n2=9, n3=62).

Link between the cluster variable and the categorical variables (chi-square test)
==
p.value df

Description of each cluster by the categories
===
NULL

Link between the cluster variable and the quantitative variables
==

	Eta2	P-value
Reduced_ketchup	0.72154854	1.175846e-27
Tatertots	0.55556528	8.292531e-18
Reduced_ketchup_Tatertots	0.43757418	7.553787e-13
Reg_ketchup_Tatertots	0.26505777	3.260471e-07
Reg_ketchup	0.20815304	1.213670e-05
Sour.2	0.15901620	2.250091e-04
Acidic.2	0.13787224	7.502811e-04
Sour.4	0.13468614	8.972688e-04
Tomato.1	0.10055688	5.857666e-03
Acidic.4	0.09054463	1.002069e-02
Greasy	0.08798970	1.148121e-02
Tomato.2	0.08340449	1.464265e-02
Sour_aftertaste.2	0.07152556	2.734278e-02
Sour_aftertaste.4	0.06853296	3.196122e-02
Astringent.4	0.06468071	3.904404e-02
Acidic.1	0.06213420	4.454756e-02
Potato	0.05994263	4.988687e-02

Description of each cluster by quantitative variables
===
$`1`

	v.test	Mean in category	Overall mean	sd in category	Overall sd	p.value
Sour.4	3.581956	2.1379310	1.63	0.6809799	0.9017206	3.410318e-04
Sour.2	2.959798	2.4137931	1.97	0.7200211	0.9534674	3.078403e-03
Greasy	2.951385	1.8965517	1.50	0.8027894	0.8544004	3.163525e-03
Acidic.4	2.946451	1.9310345	1.53	0.9443492	0.8655056	3.214432e-03
Acidic.2	2.904034	2.3448276	1.93	0.7554794	0.9083502	3.683877e-03
Acidic.1	2.480108	2.1034483	1.79	0.8845349	0.8036790	1.313424e-02
Salty	2.429115	1.3448276	1.11	0.5430350	0.6147357	1.513573e-02
Sour_aftertaste.4	2.409280	1.6896552	1.33	1.0205965	0.9492629	1.598404e-02
Metallic.4	2.260943	0.8275862	0.56	0.9123280	0.7525955	2.376282e-02
Greasy.4	2.227051	1.2068966	0.93	0.8858781	0.7906327	2.594385e-02
Astringent.4	2.200523	0.9655172	0.69	0.9642849	0.7961784	2.776984e-02
Sour.1	2.195962	2.1379310	1.82	0.6809799	0.9206519	2.809465e-02
Acidic.3	2.185953	1.7931034	1.48	0.9958296	0.9108238	2.881901e-02
Astringent.1	2.039682	1.0689655	0.78	0.9443492	0.9008885	4.138203e-02
Astringent.2	2.007188	1.0689655	0.77	0.9801842	0.9471536	4.472963e-02
Reg_ketchup	-3.450143	5.0689655	6.06	2.0159884	1.8265815	5.602891e-04
Reg_ketchup_Tatertots	-4.109790	5.4137931	6.52	1.8479670	1.7116074	3.960193e-05
Reduced_ketchup_Tatertots	-6.038636	5.1724138	6.69	1.6414662	1.5980926	1.554224e-09
Reduced_ketchup	-8.275570	3.4827586	5.90	1.1023702	1.8574176	1.278430e-16

$`2`

	v.test	Mean in category	Overall mean	sd in category	Overall sd	p.value
Thick.2	-2.091036	0.7777778	1.42	0.6285394	0.9610411	3.652483e-02
Thick.1	-2.092816	0.7777778	1.39	0.6285394	0.9153688	3.636554e-02

```
Reg_ketchup_Tatertots -2.169415     5.3333333      6.52    2.0000000  1.7116074 3.005115e-02
Reg_ketchup          -2.196557     4.7777778      6.06    1.8121674  1.8265815 2.805213e-02
Tomato.2             -2.217069     1.5555556      2.14    1.0657403  0.8248636 2.661837e-02
Potato               -2.259636     2.1111111      2.56    0.7370277  0.6216108 2.384386e-02
Sour_aftertaste.2    -2.539106     0.7777778      1.59    1.0304021  1.0009495 1.111361e-02
Acidic.2             -2.820914     1.1111111      1.93    0.8748898  0.9083502 4.788704e-03
Tomato.1             -3.149637     1.2222222      2.11    1.0304021  0.8819864 1.634733e-03
Sour.2               -3.183348     1.0000000      1.97    0.8164966  0.9534674 1.455827e-03
Tatertots            -7.208974     3.8888889      6.88    0.8748898  1.2983066 5.637515e-13

$`3`
                        v.test Mean in category Overall mean sd in category Overall sd      p.value
Reduced_ketchup           7.747427      7.0322581      5.90      0.9152426  1.8574176 9.377287e-15
Reduced_ketchup_Tatertots 6.441763      7.5000000      6.69      0.9289258  1.5980926 1.180939e-10
Reg_ketchup_Tatertots     5.121103      7.2096774      6.52      1.1378686  1.7116074 3.037541e-07
Reg_ketchup               4.520436      6.7096774      6.06      1.3723902  1.8265815 6.171229e-06
Tatertots                 4.490372      7.3387097      6.88      0.8020850  1.2983066 7.109902e-06
Tomato.2                  2.564646      2.3064516      2.14      0.7315187  0.8248636 1.032810e-02
Acidic.1                 -2.035402      1.6612903      1.79      0.7393011  0.8036790 4.181044e-02
Acidic.4                 -2.098427      1.3870968      1.53      0.7901580  0.8655056 3.586748e-02
Metallic.4               -2.102740      0.4354839      0.56      0.6380658  0.7525955 3.548848e-02
Astringent.1             -2.129780      0.6290323      0.78      0.8468894  0.9008885 3.318976e-02
Greasy                   -2.399211      1.3387097      1.50      0.8413420  0.8544004 1.643042e-02
Sour.4                   -2.514277      1.4516129      1.63      0.8739495  0.9017206 1.192768e-02
Astringent.4             -2.518016      0.5322581      0.69      0.6405074  0.7961784 1.180181e-02
```

3. Evaluation of soy sauce and cooked rice

There are 3 clusters (n1=28, n2=45, n3=25).

```
Link between the cluster variable and the categorical variables (chi-square test)
=================================================================================
    p.value df

Description of each cluster by the categories
=============================================
$`1`
NULL

$`2`
                         Cla/Mod  Mod/Cla   Global     p.value    v.test
Soysauce.F=2-3 per month 24.13793 15.55556 29.59184 0.005352334 -2.785027

$`3`
                         Cla/Mod Mod/Cla   Global     p.value   v.test
Soysauce.F=2-3 per month 44.82759      52 29.59184 0.006932414 2.700074


Link between the cluster variable and the quantitative variables
================================================================
                             Eta2      P-value
Reg_soysauce_Rice      0.47297691 6.122206e-14
Reduced_soysauce_Rice 0.43526700 1.631363e-12
Reg_soysauce           0.35282705 1.055521e-09
Reduced_soysauce       0.33984104 2.712094e-09
Rice                   0.18134159 7.453832e-05
Bitter.1               0.07387587 2.610880e-02
Bitter.3               0.06250916 4.660517e-02

Description of each cluster by quantitative variables
=====================================================
$`1`
                         v.test Mean in category Overall mean sd in category Overall sd      p.value
Bitter.1               2.265453     1.285714    0.9285714     1.1605769  0.9819805 2.348492e-02
Bitter.3               2.244223     1.035714    0.7142857     1.0850327  0.8921426 2.481803e-02
Sticky                -1.963647     1.607143    1.8469388     0.7240405  0.7606662 4.957099e-02
Rice                  -2.468365     5.964286    6.5816327     1.7419641  1.5578863 1.357318e-02
Reg_soysauce          -3.546880     3.964286    5.0816327     1.8024218  1.9622637 3.898217e-04
Reduced_soysauce      -4.607082     4.214286    5.5306122     1.8391990  1.7797276 4.083585e-06
Reduced_soysauce_Rice -5.710598     4.392857    5.9183673     1.4227560  1.6639851 1.125802e-08
Reg_soysauce_Rice     -6.564558     4.142857    5.9897959     1.7261494  1.7525195 5.218730e-11

$`2`
                    v.test Mean in category Overall mean sd in category Overall sd    p.value
Reg_soysauce_Rice 2.469403        6.466667     5.989796       1.146977   1.752519 0.01353386

$`3`
```

	v.test	Mean in category	Overall mean	sd in category	Overall sd	p.value
Reg_soysauce	5.634675	7.00	5.08163265	0.9380832	1.9622637	1.753892e-08
Reduced_soysauce_Rice	4.993438	7.36	5.91836735	0.6248200	1.6639851	5.931396e-07
Reduced_soysauce	4.888119	7.04	5.53061224	0.7200000	1.7797276	1.018042e-06
Rice	4.063557	7.68	6.58163265	0.9260670	1.5578863	4.833060e-05
Reg_soysauce_Rice	3.980065	7.20	5.98979592	0.8000000	1.7525195	6.889632e-05
Sticky.2	2.429163	0.08	0.02040816	0.2712932	0.1413919	1.513372e-02
Acidic	2.209046	0.20	0.08163265	0.4898979	0.3088316	2.717146e-02
Acidic.2	-2.097686	1.08	1.40816327	0.8908423	0.9016621	3.593285e-02
Bitter.1	-2.163283	0.56	0.92857143	0.6974238	0.9819805	3.051946e-02
Sour.2	-2.193947	1.04	1.40816327	0.8708616	0.9671833	2.823923e-02
Bitter.2	-2.209046	0.40	0.75510204	0.5656854	0.9264947	2.717146e-02