INSTRUMENTAL ANALYSIS, SENSORY ANALYSIS AND CONSUMER ACCEPTANCE OF STRAINED YOGURT IN FROZEN DESSERTS

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The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

INSTRUMENTAL ANALYSIS, SENSORY ANALYSIS AND CONSUMER ACCEPTANCE OF STRAINED YOGURT IN FROZEN DESSERTS

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INSTRUMENTAL ANALYSIS, SENSORY ANALYSIS AND CONSUMER ACCEPTANCE OF STRAINED YOGURT IN FROZEN DESSERTS

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ABSTRACT

There is a surging demand from consumers for healthier products that are lower in calories but maintain their original flavor and texture. Many countries around the world have worked to develop new techniques to improve our food supply and food products, including the utilization of functional foods and nutraceuticals. Utilizing Greek style yogurt (GSY) as a functional ingredient in frozen desserts will be a unique approach to enhancing the texture and flavor of frozen yogurts without sacrificing consumer acceptance. The objective of this study was to investigate various formulations of set yogurt and GSY with an ice cream mix in order to assess the physico-chemical effects and organic acid and carbohydrate changes. The second objective was to assess these formulations from a sensory perspective, with a combination of descriptive analysis and consumer acceptance to determine which treatments were preferred in relation to a control ice cream. Another objective was to investigate various statistical techniques that link the *Overall Liking* attribute among the treatments with the measured sensory and non-sensory based attributes.

A one-way ANOVA analysis with orthogonal contrasts found that that despite the lack of significant differences among macronutrients (e.g., protein, fat, and carbohydrates), significant differences could be observed among pH, titratable acidity,

hardness, gumminess, chewiness, particle size and flow behavior at small changes in the frozen dessert formulation. Treatments containing higher yogurt concentrations, especially those with Greek yogurt, were significantly different than the treatments with lower concentrations of yogurt.

The chemical compounds used to develop various standard curves functioned well for method validation and overall analysis of organic acids and carbohydrates in frozen dessert treatments. The standard curves aided in good separation on both Aminex – 87 HPX columns. The precision study suggested that extraction of all compounds was repeatable, with all compounds falling below 5% RSD, an acceptable level for analysis. The recovery study demonstrated the efficiency of this method regardless of the various food matrix that was utilized. Based on a one-way ANOVA analysis with orthogonal contrasts, citric acid, formic acid, sucrose, lactose, and glucose demonstrated a decrease in their average concentration as more of any yogurt type was applied to the various formulations; on the other hand, the concentration of lactic acid, acetic acid, propionic acid, and butyric acid increased in concentration as more of any yogurt type was applied to the various formulations.

The descriptive analysis conducted in this study showed that more than half of the flavor and texture attributes developed had significant differences across the tested products based on a mixed-model ANOVA. The control ice cream and GFYC (80% ice cream; 20% Greek-style yogurt) treatments held the highest intensity for most of the attributes with high significant differences. PCA indicated that the control ice cream had a high intensity in *sheen, gooeyness, creaminess, denseness, smoothness, gumminess, mouth coating, fat flavor, sweet flavor, milk flavor, fat aftertaste, sweet aftertaste*, and

milk aftertaste. The cluster analysis demonstrated that the intensity of *sweet flavor*, *fat flavor, milky flavor, sour flavor*, *hardness*, and *iciness* attributes was a determinant in dissimilarity of taste among the tested products. It was found that consumers were able to distinguish between provided frozen desserts and that there were significant differences in consumer preference. Among the samples, the control ice cream received the highest hedonic rating of 7.44, and the FYA, FYB and GFYA products were not significantly different from the control. Essentially, products that contain lower concentrations of yogurt were more accepted compared to other products based on their high concentrations of *gooeyness*, *creaminess*, smoothness, gumminess, *mouth coating, fat flavor, sweet flavor, milk flavor, fat aftertaste, sweet aftertaste,* and *milky aftertaste*. Overall, Greek yogurt as an ingredient within frozen desserts was accepted by panelists when a low concentration was utilized.

The statistical methodologies assessed the relationship between *Overall Liking* and variables from sensory and non-sensory data collected from frozen desserts developed with different types and concentrations of yogurts. The PCA model described *Overall Flavor, Milk Flavor, Sweet Flavor, Overall Liking, Fat Flavor, titratable acidity, hardness* (*descriptive analysis*), *sour flavor, sour aftertaste, pH, lactic acid, particle size,* and *protein* as significant attributes to explain differences among the treatments. The multiple linear regression demonstrated that *Overall Flavor, Milk Flavor, Sweet Flavor* were the most significant variables among all of the data that best predict the *Overall Liking* of treatments, despite the overfit nature of the model. The MFA model demonstrated a unique perspective in assessing the relationship between the *Overall Liking* among the frozen dessert treatments and the other 57 variables in the dataset. The

MFA model found associations among *Overall Liking* and its categorical group, *Preference Analysis,* in comparison to other variables and categories representing sensory and non-sensory data. The results indicated that there are relationships among the variables in different sensory and non-sensory categories. This statistical analysis provides evidence that the *Overall Liking* of frozen dessert treatments within this study can be assessed from both a sensory and non-sensory perspective in the same model.

Overall, the addition of Greek-yogurt as a functional ingredient within a frozen dessert system appears to yield an acceptable product by consumers at concentrations at or below 10%. Across the various studies in this dissertation, it was found that there were no or minimal statistical differences between the control ice cream and frozen desserts that contained low concentrations of yogurt (e.g., frozen yogurt with 10-15% yogurt and frozen yogurt with 10% Greek-yogurt).

Chapter 1

Introduction

With the popularity of dairy foods grossing more than $125 billion per year, there is a surging demand from consumers for healthier products that are lower in calories but maintain their original flavor and texture (International Dairy Foods Association 2017). Dairy products, such as chocolate milk, custards, shakes, yogurts and ice creams, have been infused with ingredients that negatively contribute to our health. The composition of these products in our diet is becoming important because of an apparent relationship between the amount and type of ingredients consumed (e.g., fat, sugar, salt) and the incidence of various chronic diseases, such as cardiovascular disease (CVD), type 2 diabetes, and obesity (Clifton 2012; U.S. Department of Agriculture 2015). Although all age groups within the United States meet or exceed the Recommended Dietary Allowance (RDA) for their average protein intake, there has been a steady increase of obesity amongst the adolescent population from 1999 to 2016 (Cifelli CJ 2015; National Center for Health Statisitics 2017). Type 2 diabetes affects up to 29 million Americans, estimating that approximately one in three Americans born today will develop diabetes over his or her lifetime (Narayan and others 2003). To reduce the risk of these various chronic diseases, the 2015-2020 Dietary Guidelines for Americans recommends diets that support healthy eating patterns for all; This includes focusing on nutrient dense foods, including seafood, lean meats, eggs, legumes (beans and peas) – and fat-free or low-fat dairy products, including milk and yogurt (U.S. Department of Agriculture 2015). The Center of Disease Control and Prevention further recommends adjusting to a healthier

diet not for short term benefits, but as a new way of life to reduce chronic diseases and maintain homeostasis (CDC 2015). As medical researchers and nutritionists investigate improving ones' health through diet, food scientists can also aid by developing foods that are of high quality, functionality, and are beneficial to those who consume them.

With an increase in public awareness of health and proper diet, considerations for the quality of various macronutrients (e.g., proteins, carbohydrates) and micronutrients (e.g., minerals and vitamins) on health are becoming more important to consumers. Many countries around the world have worked to develop new techniques to improve our food supply, including the utilization of functional foods and nutraceuticals. Nutraceuticals are seen as healthful products formulated and taken in dosage form (capsules, powders, etc.) (Hasler 1998). Functional foods were later redefined as foods being cooked or prepared using "scientific intelligence." In other words, they are foods containing a higher abundance of vitamins, fats, proteins, carbohydrates and/or other micronutrients that provide an additional physiological benefit to the consumers (Kalra 2003). Functional ingredients can be extracted from functional foods and applied to other foods that lack certain macro- or micro-nutrients. These ingredients can be anything from carotenoids, dietary fibers, proteins, probiotics, and even phenolics (El Sohaimy 2012). Although the utilization of functional foods can be applied to the formulation and manufacturing of frozen dairy products, there have been difficulties in producing healthier products containing less salt, fat, and sugar while maintaining the characteristics of their original counterpart (Biguzzi and others 2014). The utilization of functional foods and ingredients is challenging due to the unequal regulations of functional foods internationally (Domínguez Díaz and others 2020), the quality of the functional ingredient and its

interaction within a given food matrix (Wagner 2019), and their overall public acceptance.

Utilizing Greek style yogurt (GSY) as a functional ingredient in frozen desserts will be a unique approach to enhancing the quality of frozen yogurt without sacrificing consumer acceptance and sales. There is an increasing consumer demand for healthy products with clean label ingredients. Greek style yogurt offers a unique protein composition of casein and whey, which is different from set yogurt, that can improve the melting rate, viscosity, and texture of frozen yogurt systems. The protein content will also increase from the original three grams per half cup serving size without the addition of extra protein sources and may qualify the frozen yogurt for a label claim of "a good source of protein". The amount of lactose of this product will also decrease, reducing the chance of a "sandiness" off flavor. Similar to set yogurt, the presence of lactic acid bacteria in GSY has been shown to be supportive in combating certain diseases, including: colitis, constipation, gastric acidity, indigestion, obesity, diabetes, and others (Hui and Evranuz 2012). Greek style yogurt can also act as a food carrier for the delivery of probiotics into consumers. In this manner, developing frozen desserts with Greek-style yogurt as a functional food containing multiple functional components will reduce the total amount of ingredients that are required for frozen desserts while allowing a "clean label" claim.

Although there are products on the market that utilize Greek yogurt in frozen desserts, there is no published research on these commercial products (or "frozen Greek yogurt" in general). Other commercial frozen yogurts also contain other protein sources, such as milk protein concentrate and whey protein concentrate. Since there is more than one

protein source, the effects of the protein from Greek yogurt on these frozen desserts is ambiguous. In addition, other ingredients found in those products, such as stabilizers and flavors, not only interfere with consumers' perception of a "clean label", but also prevent elucidating the specific effect of the Greek yogurt on these products. Our research will explore formulations of frozen desserts with different concentrations of set and Greek yogurt – containing only the required ingredients for a simple frozen dessert mix. Thus, any differences amongst our data can be attributed to the concentration and type of yogurt used in the frozen dessert mix. Since there are no reports of using Greek yogurt as a functional ingredient in frozen desserts in the academic literature, the exploration of its physical, chemical, and sensory attributes has great potential for understanding the impact of GSY on frozen desserts.

This research focuses on formulas designed to provide consumers with a frozen yogurt product that meets some of their major nutritional needs. Therefore, the specific objectives of this study were:

- To investigate the physicochemical effects of adding varying levels of Greek-style yogurt (GSY) to an ice cream mix
- To determine if using GSY causes differences in carbohydrate and organic acid profiles between various formulations of frozen yogurts.
- To measure consumers' degree of liking of frozen yogurts with varying levels of GSY.

- To measure a trained panel's level of discrimination between frozen yogurts with varying levels of GSY, frozen yogurts formulated with plain yogurt, and plain ice cream.
- To investigate various relationship between *Overall Liking* and sensory and non-sensory based attributes with various parametric and no-parametric statistical techniques.

Chapter 2

Literature Review

2.1 Frozen Desserts

2.1.1 Ice Cream

Ice cream is defined as a dairy foam that contains a mixture of air, water, milk fat, nonfat milk solids, sweeteners, stabilizers, emulsifiers, and flavors (E and others 2010). An average ice cream contains 12% fat, 11% non-fat milk solids, 15% sugar, 0.3% stabilizer and emulsifier, and has a total solids content of 38.3% (Arbuckle 1986). The uncommon foam structure found in ice cream is strongly influenced by the ingredient amount and selection, processing conditions, and the physical, chemical, and mechanical properties of the end-product. Once a formulation has been established, the ice cream mix is typically pasteurized by the high-temperature-short-time (HTST) method; afterwards the mix is homogenized to form an oil-in-water emulsion (E and others 2010). During the freezing process air bubbles are dispersed in a continuous phase that contains crystalline fat globules, casein micelles, insoluble mineral salts, whey proteins, sugars, and stabilizers (Góral and others 2018). Casein micelles are typically found next to the air interface and fat globules (Costa and others 2008; Marshall and others 2003). Whey will denature during the processing of ice cream, which increases its capacity to hold water (Dalgleish 1990). Since whey proteins are sensitive to most heat treatments, they bind to casein micelles or aggregate amongst themselves when exposed to temperatures above 70 °C (Dalgleish 1990; Tamime 2007). Fat globules that are present in milk will destabilize during the freezing step, but this provides strength and support for the air cells present in

the final product (Adleman and others 2001). Fat has the capability to aggregate in other ways that are harmful to the ice cream structure, including: coalescence, flocculation, partial coalescence, and clustering (Goff and others 1999). In order to prevent the degradation of certain ingredients, specific proteins, stabilizers, and surfactants are used in mixes for foaming stabilization to protect the final volume and quality of the product (Clarke 2015).

2.1.2 Frozen yogurt

2.1.2.1 Definition and criteria

Frozen yogurt was developed in the 1970's as an alternative frozen dessert to ice cream. It is a cultured frozen product that contains the same ingredients as ice cream, but provides additional sensory and nutritional properties of fermented milk products. (Arbuckle 1986). There are many soft-serve and hard-packed frozen yogurt products that are not very acidic; they typically come in low-fat and non-fat varieties (Hui and Evranuz 2012). Industry standards require that a frozen yogurt product contains at least a titratable acidity of 0.30%, where 0.15% of titratable acidity comes from fermentation products of yogurt. A typical nonfat frozen yogurt will contain 0% fat, 13% milk solids non-fat, 13% sucrose, 6% corn syrup solids 36 Dextrose Equivalent (DE), 2% maltodextrin Dextrose Equivalent (DE), and 1.2% stabilizers. The final pH will vary between 5.5 and 6.0 depending on the consumer's acceptance. (White and others 2008).

2.1.2.2 Production of frozen yogurt

Frozen yogurt products share similarities to ice cream regarding their processing; however, there are multiple methods to incorporate yogurt into a frozen yogurt mix prior to freezing (Figure 2-1). Direct acidification (one-stream method) involves blending a

yogurt culture with a homogenized ice cream mix, virtually fermenting the entire product. Indirect acidification (two-stream method) involves combining a portion of yogurt with an ice-cream mix at various proportions ranging from 5%-70%; afterwards the whole mix is aged then frozen. The addition method involves the incorporation of the lactic acid bacteria into an ice cream mix prior to the freezing step without any fermentation of the mix (Soukoulis and Tzia 2008). Similar to ice cream, a frozen yogurt mix is frozen at -6°C and hardened at -40°C after processing (Hui and Evranuz 2012). Although there are many combinations using stirred yogurt within the frozen dessert category, there is little evidence of any combination of more concentrated forms of yogurt and frozen desserts in the literature.

2.1.2.3 Frozen dessert market information

The global frozen dessert market is expected to be valued at USD 102.9 billion by 2026 and is expected to expand at a compound annual growth rate (CAGR) of 5.64% from 2021-2026 (Market Research Future 2021). In 2020, the United States frozen dessert market was valued at USD 52.82 billion compared to the rest of the world (Grand View Research 2021). This growth can be attributed to the change in consumer tastes, increased health consciousness, and the introduction of unique frozen dessert products (e.g. novel flavors, different mix formulations) that cater to the vast variety of consumers (Grand View Research 2019; Grand View Research 2021). Many reports demonstrate frozen yogurt as an important driving factor in the frozen dessert market across the globe due to its positive nutrition and digestion effects on the body, its variety of flavors, and the addition of carbohydrates, proteins, and calcium (Grand View Research 2019; Market Data Forcast 2021; Market Research Future 2021). However, certain countries, such as

the United States and China, demonstrate competing factors that drive their markets besides frozen yogurt, including specialty flavors, and water and fruit based mix formulations (Grand View Research 2021; Mordor Intelligence 2021).

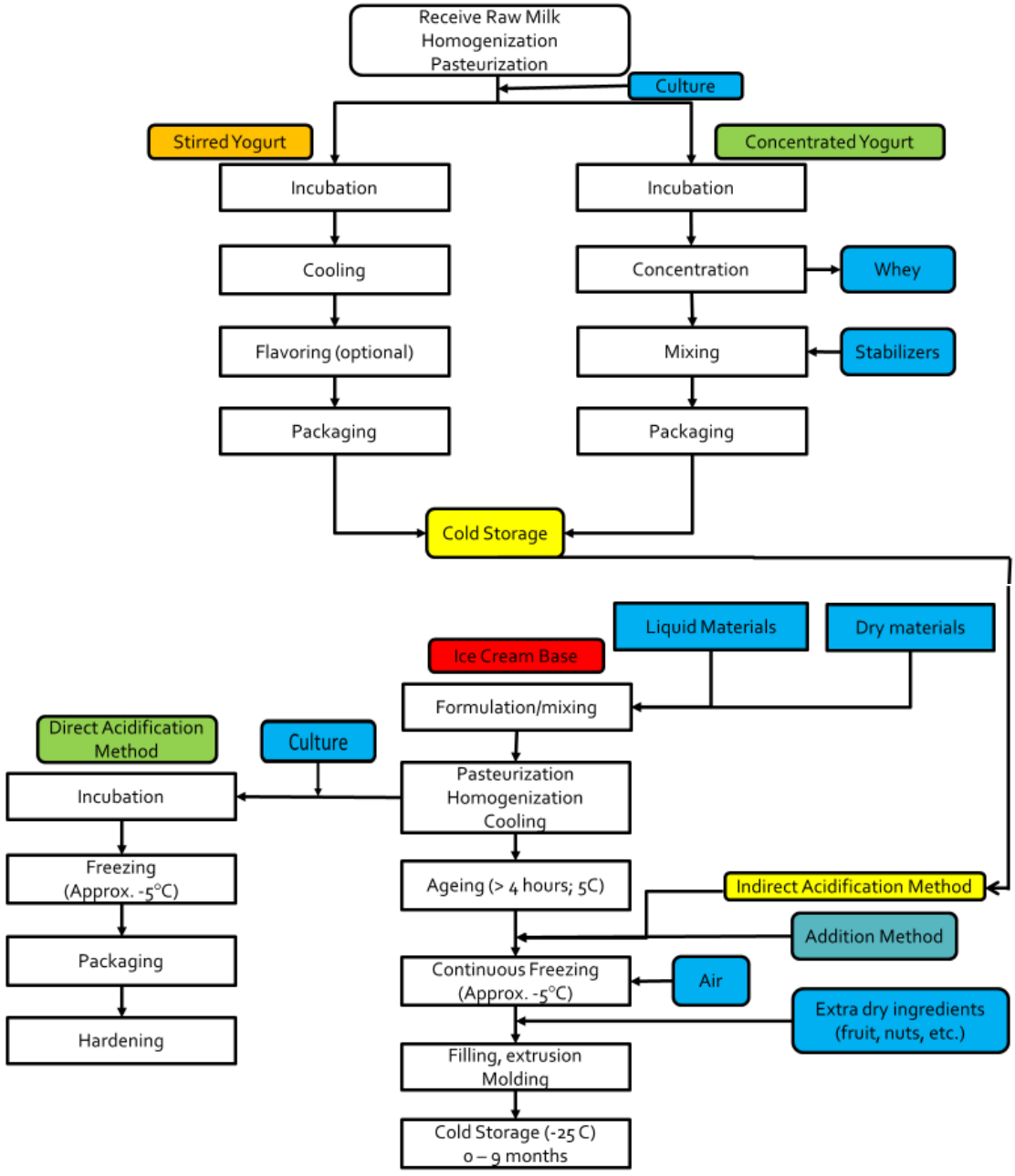


Figure 2-1 Flow diagram of the production of frozen yogurt in a simple food manufacturing plant (Bylund 2003; Soukoulis and Tzia 2008)

2.2 Functional foods and nutraceuticals

The examination of disease-fighting components and phytochemicals within food and medicinal plants have created a plethora of research in food science and nutrition research. Concepts such as “nutraceuticals” and “functional foods” have become popular in academia and industry, but they are often lumped together and confusing to differentiate (Hasler 2005). In the simplest terms, nutraceuticals are seen as healthful products formulated and taken in dosage form (capsules, powders, etc.); whereas functional foods are healthful products that are consumed as foods – not in a dosage form (Hasler 1998). The term “nutraceutical” that combines “nutrition” and “pharmaceutical” was developed in 1989 by Stephen DeFelice, MD. He defined nutraceuticals as a food or food component that provides medical or health benefits, including the prevention and/or treatment of a diseases (De Felice 2002). The concept of nutraceutical foods was refined into functional foods and nutraceuticals to improve their identification within the food industry. Functional foods were later redefined as foods being cooked or prepared using "scientific intelligence" with or without knowledge of how or why it is being used. In other words, they are foods that contain a higher abundance of vitamins, fats, proteins, carbohydrates and/or other micronutrients that provide an additional physiological benefit to the consumers (Kalra 2003). Some of these foods are not used to prevent illnesses (El Sohaimy 2012). When a functional food is utilized to prevent and/or treat diseases or disorders other than anemia, it is considered a nutraceutical (Kalra 2003). As a result, a food component can be a functional food to one consumer and a nutraceutical to another. A list of functional food components and their health benefits was compiled to illustrate the different benefits of functional foods (Table 2-1).

Further classification of functional foods was established to explain their use in various food categories. Although there is an abundance of functional food applications in all food categories, the distribution of those applications is unequal and dissimilar (Bigliardi and Galati 2013). Markets that utilize functional foods the most are based in dairy, confectionary, soft-drink, bakery, and baby-food (Kotilainen 2006). From a product development perspective, Kotilainen (2006) and Spence (2006) proposed the following classification labels for functional foods:

- **Fortified foods** – foods fortified with additional nutrients such as fruit juices fortified with vitamin C, vitamin E, folic acid, zinc, and calcium.
- **Enriched products** – foods with additional new nutrients or components not normally found in the particular food, such as probiotics or prebiotics.
- **Altered products** – foods from which a deleterious component has been removed, reduced or replaced by another with beneficial effects, for example fibers as fat replacers in meat or ice cream.
- **Enhanced commodities** – foods in which one of the components have been naturally enhanced e.g., eggs with increased omega-3 content.

Table 2-1 Examples of functional food components adapted by El Sohaimy (2012)

Functional components	Source	Potential benefits
Carotenoids		
Alpha-carotene Beta-carotene	Carrots, Fruits, Vegetables	Neutralize free radicals, which may cause damage to cells
Lutein	Green vegetables	Reduce the risk of macular degeneration
Lycopene	Tomato products (ketchup, sauces)	Reduce the risk of prostate cancer
Dietary Fiber		
Insoluble Fiber	Wheat Bran	Reduce risk of breast or colon cancer
Beta-Glucan	Oats, barley	
Soluble Fiber	Psyllium	Reduce risk of cardiovascular disease. Protect against heart disease and some cancers; lower LDL and total cholesterol
Fatty Acids		
Long chain omega-3 Fatty Acids-DHA/EPA	Salmon and other fish oils	Reduce risk of cardiovascular disease. Improve mental, visual functions
Conjugated Linoleic Acid (CLA)	Cheese, meat product	Improve body composition. Decrease risk of certain cancers
Phenolics		
Anthocyanidins	Fruits	Neutralize free radicals; reduce risk of cancer
Catechins	Tea	
Flavonones	Citrus	Prevention of cancer, renal failure
Flavones	Fruits/vegetables	
Lignans	Flax, rye, vegetables	Improve urinary tract health.
Tannins (proanthocyanidines)	Cranberries, cranberry products, cocoa, chocolate	Reduce risk of cardiovascular disease
Prebiotics/Probiotics		
Fructo-oligosaccharides (FOS)	Jerusalem artichokes, shallots, onion powder	Improve quality of intestinal microflora, gastrointestinal health
Lactobacillus Yogurt, other fermented dairy products	Yogurt, other dairy	
Soy Phytoestrogens		
Isoflavones	Soybeans and soy-based foods	Protect against heart disease and some cancers; lower LDL and total cholesterol. Menopause symptoms, such as hot flashes Protect against heart disease

Functional foods can be divided into functional ingredients, fractions or extracts from functional foods containing bioactive compounds of varying purity that are used as ingredients by manufacturers in the food and pharmaceutical sectors (Hasler 1998). The use of these ingredients with foods or on their own will determine their final classification in foods. For example, applying probiotics, a functional ingredient, into yogurt would be classified as an enhanced product or a nutraceutical depending on the consumers health goals. However, probiotics consumed in capsule form would be considered a nutraceutical. Recent trends show that consumers are searching for functional ingredients to enhance the nutritional value of a wide variety of modern foods, including frozen desserts, in order to satisfy a growing consumer base of health conscious customers, including those who are lactose intolerant and vegan (Serventi 2020). The following sections of functional ingredients highlight features that enhance the quality of frozen desserts.

2.2.1 Proteins

Many proteins play a pivotal role in stabilizing food products because of their inherent amphiphilic properties; proteins have both hydrophobic and hydrophilic regions (Kinsella and Morr 1984). Proteins are bioactive compounds consisting of long-chain polymers of amino acids. Among other protein sources, soybean proteins have a significant effect on lowering cholesterol levels in the blood by preventing cholesterol production in liver cells (Beecher 1999). Another health benefit of proteins comes from the indigestible proteins; these substances help the large intestine expel toxins and bile from the body and reduce absorption of consumed cholesterol (El Sohaimy 2012). Buckwheat and soybean proteins exemplify this trait as they both contain large amounts

of indigestible proteins that maintain a clean and healthy gut if enough of the substance is consumed. Finally, bioactive peptides demonstrate other positive attributes for health, including antimicrobial and antifungal properties, blood pressure lowering effects, cholesterol lowering abilities, antithrombic effects, mineral absorption and immunomodulatory effects (El Sohaimy 2012)

Amongst all of the proteins, various forms of whey protein have dominated the food industry and academic literature. Whey protein is widely used in the frozen dessert industry due to its ability to provide consistent quality. Goff and others (1989), have demonstrated how applying higher concentrations of whey protein isolates and caseinates to ice cream mixes improves their overall quality. They discovered that whey protein isolate, at above 90% concentrate, provided more desirable properties in a final ice cream product compared to mixes with whey protein concentrate at 36%; the application of sodium caseinate into ice cream mixes improved the overrun of the product, but reduced the overall quality. In a study comparing the application of whey protein isolate (WPI) and inulin, possible fat replacers for reduced-fat and non-fat ice creams, Akalın and others (2008) demonstrated that WPI had a higher quality of rheological properties compared to inulin. Although there was minimal color and melting resistance differences between WPI and inulin, inulin produced higher hardness attributes and faster melting rates compared to regular ice cream. El-Zeini and others (2016) recommends substituting up to 3% of the non-fat milk solids (NFMS) of an ice cream mix with WPI to generate higher quality products. Experimental ice creams that replace skim milk powder (SMP) with WPI were shown to have significant more protein, ash, and lactose content; Mixes

produced with WPI and less SMP were also smoother and more accepted in sensory studies compared to mixes with no added WPI.

Although various forms of whey are used to enhance the nutritional quality of frozen desserts, non-dairy based proteins are becoming more popular in order to improve the ingredient quality within ice cream. Proteins originating from plants are considered an invaluable alternative to animal proteins and petroleum derived polymers (Clemente and others 2015). For example, frozen dessert mixes that replace SMP with soy extract improves the protein content, pH, and melting resistance compared to mixes containing only SMP (das Graças Pereira and others 2011). According to this study, soy extract can substitute up to 20% of the SMP in a frozen dessert mix before experiencing negative attributes in sensory tests. Further steps to improve the quality of ice cream were taken by Jain and Rai (2018) as they substituted fat with inulin, sugar with stevia extract, and SMP with soy protein to produce a healthier frozen dessert. They discovered that the substituted ingredients, used in a controlled amount, can create an acceptable product for consumers who are suffering from various chronic diseases such as diabetes, obesity, etc. Recently, research has shown that pea protein isolate (PPI) has great potential to replace WPI in ice cream. According to work from Mendes and others (2018), PPI is thermally stable and has stable surfactant activity post spray drying, important factors that are required for stable emulsions in frozen desserts. As surfactants are known to be amphiphilic in nature, it has been proposed that surfactants from PPI can also function as emulsifiers in food matrices because of the opposing physico-chemical forces of polysaccharides and proteins (Guo and others 2020).

2.2.2 Probiotics

Probiotics are organisms that "beneficially affect the host animal by improving its intestinal microbial balance" (Fuller 1989). An imbalance of bacteria in the gut is likely to occur when certain consumers go through stress, antibiotic therapy, and poor eating choices; harmful gut bacteria can out-compete beneficial gut bacteria and decrease the functionality of the immune system (El Sohaimy 2012). Studies have shown that approximately 10^7 cfu of living organisms per gram or volume of consumed probiotics can be considered as an ingredient that can restore the balance of bacteria residing in a consumers' digestive tract (Charalampopoulos and others 2003; Guarner 1998). This minimum volume is recommended as the number of bacterial units in one product will decrease while going through the digestive system. In this manner, probiotics can be utilized within foods as a functional ingredient or as a nutraceutical. According to Kolida and Gibson (2011) and Shewale and others (2014), microorganisms can be considered as probiotics for food products if the following criteria are fulfilled:

- **Safety** – The ability to survive within the human gastrointestinal (GI) tract. Probiotics isolated from the GI tract are considered safer than commercially developed probiotics.
- **Resistance** – The ability to resist high acidic conditions from bile acid within the stomach.
- **Growth and overall health benefit** – The ability to grow within a host intestine and provide a beneficial effect for the host. The more efficient a probiotic can grow, the better it can suppress pathogenic bacteria, improve lactose digestion,

improve immune response, decrease diarrhea symptoms, and demonstrate antitumor effects (Marteau and Boutron-Ruault 2002; Reid and others 2001).

- **Feasibility** – The ability to be prepared in a large, viable concentration.
- **Compatibility** – The ability to survive in a food matrix, especially if fermentation is necessary.
- **Stability** – The ability to remain stable during food processing conditions (e.g., freezing) and storage conditions (e.g., refrigeration, room temperature).
- **Flavor** – The ability to provide minimal changes to flavor and texture within food products.

As a result of their increased popularity, many strains of probiotics have been developed to provide a variety of health benefits to consumers (Table 2-2). Common strains of probiotics found within foods include the facultative anaerobic bacterium *Lactobacillus ssp.* and the non-motile, anaerobic *Bifidobacterium* (Ziemer and Gibson 1998).

Table 2-2 List of Probiotics adapted from Prado and others (2008)

Lactobacillus species	Bifidobacterium species	Other Species
L. acidophillus	*B. adolescentis*	*Bacillus cereus*
L. amylovorus	*B. animalis*	*Clostridium botyricum*
L. brevis	*B. breve*	*Enterococcus faecalis*
L. casei	*B. bifidum*	*Enterococcus faecium*
L. rhamnosus	*B. infantis*	*Escherichia coli*
L. crispatus	*B. lactis*	*Lactococcus lactis* subsp.
L. delbruckii subsp.	*B. longum*	*cremoriss*
bulgaricus		*Lactococcus lactis* subsp *lactis*
L. fermentum		*Leuconostoc mesenteroides* subsp.
L. gasseri		*dextranicum*
L. helveticus		*Pediococcus acidilactici*
L. johnsonii		*Propionibacterium freudenreichii*
L. lactis		*Saccharomyces boulardii*
L. paracasei		
L. platarum		
L. salivarius		
L. gallinarum		

Probiotics have been used in fermented food products for hundreds of years. The addition of *Lactobacillus* and *Bifidobacterium* species to foods has been shown to increase their health benefits (Shah 2000). Dairy products are typically paired with the probiotic cultures of *L. acidophilus*, *Bifidobacterium* spp. and *L. casei* (De Vrese and Schrezenmeir 2008). Yogurt is the most popular food vehicle for probiotics among dairy products. The viability of those microorganisms within yogurt depends on the characteristics of the food matrix, including: the availability of nutrients, growth promoters, growth inhibitors, mineral concentration, inoculation levels, incubation temperatures, fermentation time, and storage temperatures (Shah 2000; Talwalkar and Kailasapathy 2004). According to Song and others (2012), the pH value of yogurt is the main factor that determines the growth and viability of applied probiotics. However, the strain of the probiotic and the interactions between other microbial species within a given food matrix can also affect negatively affect the stability of an applied probiotic (Vasiljevic and Shah 2008).

Frozen dairy desserts are also showing the most potential as vehicles of probiotics with ice cream since they are consumed by people of all ages. Cruz and others (2009) explained the technological parameters involved with ice creams with probiotics, stating that factors such as appropriate selection of cultures, inoculums concentrations, processing procedures, transport and storage temperatures need to be controlled to maintain probiotic quality. In one study, probiotic ice creams formulated with prebiotic ingredients, such as inulin and oligofructose, had a higher probiotic survival rate during storage compared to probiotic ice creams with no prebiotics (Akalın and Erişir 2008). Work from Başyiğit and others (2006) demonstrated that ice creams formulated with

various human probiotic bacteria, such as *L. acidophilus*, produced minimal concentration differences despite the formulations containing various concentrations of sucrose and aspartame. Lin (2012) formulated ice creams containing multiple functional ingredients such as probiotics (*Lactobacillus rhamnosus* HN001), prebiotics (inulin), dietary fibers (digestive resistant maltodextrin), and antioxidants from açai. There were no significant differences in consumer preference between the developed formulations of multifunctional ice creams, but there were descriptive and instrumental differences based on different concentrations of inulin and antioxidants.

2.2.3 Carbohydrates

In some cases, improving the nutritional quality of frozen desserts can be completed by removing or replacing a nutritionally inferior ingredient, thus creating an altered product. It would be ideal to remove a significant amount of lactose, a disaccharide found in milk, utilizing enzymatic methods. El-Neshawy and others (1988) discovered that lactose reduced milk demonstrated a decrease in sandy textures found in ice creams. However, Marshall and others (2003) discovered that developing ice cream with ultra-filtered skim milk – or milk with very little lactose – increased the hardness and decreased the melting rate of the final product. Matak and others (2003) worked to reduce the lactose content of ice creams by hydrolyzing the lactose within an ice cream mix using β-galactosidase from *Kluyveromyces lactis* and *Aspergillus oryzae*. Their experimental formulations also demonstrated negative characteristics, producing softer, less sweet, and low viscosity products compared to a control ice cream. Abbasi and Saeedabadian (2015) had similar results to Matak when hydrolyzing lactose in mixes, but when formulated with reduced added sugar, experimental formulations containing a 25%

sugar reduction and a 75% hydrolyzation created a higher resistance to melting and showed the most similarity to a control ice cream.

Many sugar alternatives have been considered in order to reduce the calories of dairy products while maintaining a consistent sweet flavor (Table 2-3). It is difficult to develop a consistent model between sweeteners and food matrixes as every food matrix is different; while some products contain more fat, others are produced at lower temperatures and affect the overall flavor. Isomalt has been considered a successful sweetener in frozen yogurt without any extra sucrose added compared to sweeteners such as polydextrose, aspartame, and stevia (Isik and others 2011). Narayanan and others (2014) demonstrated that stevia could be used in conjunction with mildly sweet bulk fillers to improve low-fat yogurt. In an effort to develop low calorie ice creams by utilizing different combinations of sucrose and stevia, Alizadeh and others (2014) discovered that ice creams with a higher concentrations of sucrose were preferred compared to lower calorie formulations with higher concentrations of stevia.

Table 2-3 Sweeteners used in the dairy industry adapted from McCain and others (2018)

Category and Sweetener	Characteristic	Pros	Cons	Sucrose Equivalent
Nutritive sweeteners				
Sucrose	Stimulates sweet protein receptor in taste cells	Adds color and flavor; lowers water activity; preservative	Adds unnecessary calories to diets	1
fructose	considered the sweetest sugar found in nature	Natural carbohydrate	Does not affect satiety in the same way as glucose	1.2-1.8x
Lactose	Disaccharide naturally present in milk	Natural; important starting material for probiotic bacteria	Accounts for 30% of the caloric value of whole milk but provides little sweetness	0.11-0.125x
Tagatose	Rare natural hexo-ketose found in dairy products	Lower glycemic index and virtually zero calories (1.5 kcal/g)	Rare in nature and has to be produced artificially using a calcium catalyst	0.92x

Table 2-3 Sweeteners used in the dairy industry adapted from McCain and others (2018) (cont.)

Category and Sweetener	Characteristic	Pros	Cons	Sucrose Equivalent
Natural nonnutritive sweeteners				
Stevia rebaudiana	Found as Stevioside or Rebaudioside A	Natural; stable at high temperatures, generally regarded as safe (GRAS)	Off-flavors reported; differences between ingredient suppliers	210x
Sirraitia grosvenorii (monk fruit)	Also known as Mogroside V	Natural, GRAS	Associated with bitter and metallic tastes	250-425x
Artificial nonnutritive sweeteners				
Surcalose (Splenda)	Replaces 3 H–O groups on the sucrose molecule with 3 Cl atoms	Temporality most similar to sucrose; easiest nonnutritive sweetener substitute for sugar	Metallic aftertaste, artificial	750x
Aspartame (Equal)	Composed primarily of 2 amino acids, phenylalanine and aspartic acid	More pleasant taste than stevia; FDA approved	Artificial; not heat stable so cannot be used in baking applications; not pH stable	200x
Saccharin (Sweet 'N Low)	Shape and hydrogen are important to sweet taste	FDA approved	Metallic aftertaste, artificial	400x
Sugar alcohols				
Xylitol	One-third of the calories of sucrose (1.32 kcal/g),	Can be substituted on a weight-by-weight basis for sucrose	Potent laxative effect and other gastrointestinal symptoms when 50g is ingested	1x
Sorbitol	Obtained from aldose sugars	Naturally present in some fruits and vegetables, bulking agent	Similar to xylitol	0.5-0.7x
Erythritol	Highly stable, low calorie (0.2 kcal/g),	tooth-friendly; bulk sweetener that provides volume, texture, and microbiological stability	Gastrointestinal symptoms observed with more than 1,000 mg/kg of BW	0.7x
Lactitol	Low calorie (1.9 kcal/g),	low-fat, and sugar-free food for diabetics	Similar to xylitol	0.3-0.4x
Isomalt	Low calorie (2 kcal/g)	tooth-friendly; resistant to loss of sweetness from heating	Similar to xylitol	0.45-0.65x

2.3 Opportunities and challenges of functional food and nutraceuticals

2.3.1 Public motivation and acceptance

The functional food and nutraceuticals industries have grown exponentially over the past few decades due to society's increasing curiosity in the link between food and health. In spite of inconsistent information, there is an increased interest in the positive role diet can play in preventative health and an increased quality of life (El Sohaimy 2012). A study about food with functional abilities within the United States established that 95% of the population believe that food has the potential to improve health beyond simply delivering nutrients (Dixon and Steele 1999). Governments also recognize the economic potential of functional foods as another strategy for public health promotion, but the savings that could be earned from an increased use of functional foods and the reduction of health and pharmaceutical costs have not been assessed (El Sohaimy 2012). Countries around the world have varying processes for the systemic investigation of linking functional foods to physiological mechanisms that affect diseases. This creates a mixed reaction of acceptance and skepticism by consumer on the overall effectiveness of functional foods. Sweden and Japan are considered pioneers in this investigation since they employ the cooperation of food companies, research organization, and authorities to provide a consistent regulatory system for marketing (Mark-Herbert 2002). On the other hand, the United States only utilizes an independent group of scientists to compare clinical data for the health claim submissions with functional foods (Jones 2002).

2.3.2 Regulations and health claims

Regulatory organizations throughout Europe, America, and Japan have developed frameworks to establish consistent labeling of products containing health benefits and

functional foods. However, the regulatory framework and approval and use procedures are different between contries. In 1991, Japan has established the FOSHU – Foods for Specialized Health Use – legislation that allows more than 200 functional foods to be marketed with a “FOSHU” labe1 (Monge and others 2008). Foods containing ingredients that have been FOSHU approved do not require further testing for health claims; these foods or ingredients on their approved list are regulated for their safety, health, and the quantity of effectiveness by the Japanese Department of Health (Shimizu 2002). The approved foods and ingredients are classified into familiar food categories such as proteins and carbohydrates.

The use of functional foods and health claims in Europe is slightly different from Japan. Any food that does not have solid scientific evidence for a qualified health claim is not permitted for use in Europe. Foods containing functional ingredients and proposed health claims need to be assessed by a regulatory process conducted by the European Food Safety Authority (EFSA). EFSA and the European Commission with scientific assessments required prior to approval for public use. The overall goal of these regulatory agencies is to provide clear health claims that pertain to the reduction of diseases (Duttaroy 2019).

In the United States, the FDA has the authorization to assess health-related claims on food products based on the 1990 Nutrition Labeling and Education Act (NLEA). This act grants the FDA the power to allow certain disease-risk-reduction claims, known as “health claims,” on food labeling. If required, the food is categorized under three types of health claims under the NLEA: authorized, qualified and structure function claims (Clydesdale 2004). A large portion of products containing these claims do not have solid

scientific evidence compared to products with “health claims” in Europe and Japan (Domínguez Díaz and others 2020). As a result of loose FDA regulations, American companies capitalize on soft claims that imply health effects without actually naming target diseases. Canada, Australia, and New Zealand have introduced new systems to regulate health claims, but their lack of quality regulations lead to functional food products with varying effectiveness to prevent or reduce many diseases (Hu 2003). Table 4 describes the major labeling regulations of major regions around the world.

Table 2-4 Functional food and nutraceutical labeling regulations from various countries adapted from Shimizu (2002), Duttaroy (2019), and Domínguez Díaz and others (2020)

	Japan	**Europe**	**United States**
“Health Claim” Type	Nutrition/function	Nutrition content/ Health	Nutrient Content
Regulation/ Authority	FOSHU	EFSA	NLEA/ FDA
“Health Claim” Goal	Reduction of disease risk	Reduction of disease risk	General health claim

2.3.3 Ingredient quality

As stated above, functional foods, or foods that contain biologically active compounds, are growing in demand as they can deliver properties that alleviate various illnesses. They enhance the quality of foods with pre-established macronutrients, e.g., proteins, lipids, carbohydrates, and micronutrients, such as minerals and vitamins. The maintenance of their biological activity requires a minimization of interactions between these bioactive compounds with other food components commonly found in food matrixes. Interactions can happen through physical, chemical, or physicochemical means.

Physical interactions involve subjecting ingredients or products to adsorption, absorption, evaporation, drying, and particle size reduction. Chemical interactions can occur between macronutrients (e.g., protein – protein, protein – lipid, protein – carbohydrate) between macronutrients and micronutrients, e.g., protein – enzyme, and even between nutrients and packaging materials. Physiochemical interactions involve the generation of foams, emulsion, gels, and from initial food components that were simple homogenous solids, liquids, or gases (Gaonkar and McPherson 2016).

The ingredient quality plays an enormous role in a product's flavor, texture, and processing. In a presentation about the challenge of formulating plant-based frozen desserts, Wagner (2019) explains that varying macronutrient and micronutrient differences between plant based ingredients and dairy based ingredients can influence product characteristics during production. For example, although plant-based ingredients, such as pea protein, may have a higher protein content in comparison to dairy ingredients, the functional properties of plant-based ingredients are harder to predict due to their variable composition and processing. This leads to unpredictable properties in emulsification properties, fatty acid composition and freezing point depression. Wagner also notes that despite similar sensory characteristics between milk and plant liquids, the difference contributes to off-note flavors that need to be masked or complemented for consumer acceptance. The interaction amongst applied ingredients should also be considered when improving a food product. Buriti and others (2007) noted in their study that in an ideal world, fruits and/or flavoring additives with low acidity values should be considered when developing products containing probiotics; however, despite the low acidity these ingredients would bring, certain fruits such as passionfruit will have

intrinsic factors that will inhibit the viability of probiotic microorganisms – essentially making the probiotic ingredient useless.

2.4 Milk Benefits

Compared to most functional ingredients and nutraceuticals, dairy foods are typically considered balanced and nutritive foods (Pereira 2014). Products such as milk, cheese and yogurt can act as great delivery systems for many nutrients that are important for good health (Brown-Riggs 2016). Customary bovine milk is composed of approximately 87% water, 4%-5% lactose, 3% protein, 3%-4% fat, 0.8% minerals, and 0.1% vitamins, including calcium, potassium, vitamin A, and vitamin D (Haug and others 2007; Jandal 1996). Of all the various components of milk, milk proteins have a high biological value due to their high essential amino acid content (Haug and others 2007).

Most food-derived bioactive peptides thus far have been isolated from milk-based products. Whey proteins and casein represent the majority of the proteins in milk. They are both considered high quality proteins because of their digestibility, bioavailability, and they contain essential amino acids for human nutrition (Pereira 2014). Whey contains an abundance of branched chain amino acids, including leucine, isoleucine, valine, and lysine, whereas casein contains a higher amount of histidine, methionine, and phenylalanine (Tang and others 2009). Among the protein fractions within whey protein, lactoferrin and lactoperoxidase act as antimicrobial agents (Jenssen and Hancock 2009). Lactoferrin also serves a critical role in iron absorption as it demonstrates antioxidant and anticarcinogenic effects within humans (Mills and others 2011). Caseins provide support as mineral binding carriers for calcium and phosphorus (Holt and others 2013). However, they also produce multiple bioactive peptides that provide antioxidant (Fiat and others

1993), antihypertensive (Jauhiainen and Korpela 2007), and antithrombotic properties – properties that benefit the cardiovascular, nervous, and immune systems of humans (Phelan and others 2009).

The proteins found in milk and milk products can be a great macronutrient source to help improve the diets of many people. A ranking of the satiating efficacies of protein, carbohydrate and fat show that proteins are considered the most satiating and fat the least (Veldhorst and others 2008). It has been demonstrated that mixed proteins consisting of meat, fish, plants or dairy products can provide a good satiating effect to subjects who are in energy balance and weight stable (Barkeling and others 1990). There is sufficient evidence to demonstrate that eating less energy dense, high-protein snacks, such as yogurt, can improve appetite control and satiety of a group of healthy adult volunteers (Ortinau and others 2014). Another study on snacks, varying in protein content influencing appetite-control and eating initiation, concluded that strained yogurt, containing 24 g protein, led to reduced hunger, increased fullness, and delayed subsequent eating compared to lower protein snacks in healthy women (Douglas and others 2013). Consuming the recommended daily amounts of dairy can help close nutrient gaps and potentially displace other less nutritious options in the diet. Moreover, moderate evidence shows that intake of milk and milk products is linked to improved bone health, especially in children and adolescents. Moderate evidence also indicates that intake of milk and milk products is associated with a reduced risk of cardiovascular disease and type 2 diabetes and with lower blood pressure in adults (Rice 2014; Rice and others 2013; U.S. Department of Agriculture 2015).

2.5 Yogurt

2.5.1 Definition & criteria

Fermented milk products such as yogurt are considered “functional foods” because they have health benefits beyond conventional nutrition (Hui and Evranuz 2012). Yogurt is defined by the United States FDA (FDA 2011) as a food produced by culturing a standardized yogurt mix with bacterial cultures that produce lactic acid; the final product should contain bacteria including *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. A standard yogurt product contains at least 3.25% milk fat, 8.25% milk solids non-fat (MSNF), and a titratable acidity of at least 0.9% expressed as lactic acid. The yogurt mix, containing cream, milk and partially skimmed or skimmed milk, is homogenized and then pasteurized or ultra-pasteurized before the addition of bacterial cultures and extra flavors. As long as the protein efficiency ratio of all protein present within yogurt is not decreased, one or more of the following optional ingredients is allowed to be applied to yogurt, including: concentrated skimmed milk, nonfat dry milk, buttermilk, whey, lactose, lactalbumins, vitamins A and D, nutritive carbohydrate sweeteners, flavoring ingredients, color additives and stabilizers. Low-fat and nonfat yogurts are produced in a similar manner to full fat yogurt, except for the overall concentration of milk fat in the product. Low-fat yogurts need to have between 0.5%-2.0% milk fat while nonfat yogurts need less than 0.5% milk fat. A yogurt product needs to have at least 10^8 cfu/g at the time of manufacturing to meet the standard for containing active yogurt cultures (Hui and Evranuz 2012). Yogurt can also be classified into the following products:

- **Plain yogurt** – Contains no added sugar and is made by cup or vat incubation.
- **Fruit-flavored yogurt** – A popular product worldwide
    - **Stirred or swiss-style yogurt** – Fully fermented and plain yogurt is cooled to approximately 20 °C and pH 4.3-4.4. The product is blended with a specific fruit preparation, but the texture and physical properties of the product depends on the ingredients and food processing utilized such as stabilizers and rate of cooling
    - **Set-style fruit-on-bottom** – Products are prepared by applying a fruit preparation (15%-20% by weight) into serving cups, heat treating those cups at approximately 48 °C and applying plain yogurt cooled at 16 °C on top of the fruit perpetration.
    - **Light yogurt** – A yogurt with no added sugar; Sweeteners are either applied to the yogurt product or to the fruit preparation.
    - **Custard-style yogurt** – A fruit flavored yogurt with a high starch content that produces a custard-like texture.
- **Yogurt whips/mousse** – A fluffy product that utilizes air and gelatin to produce a foam-like yogurt. This product contains more sugars and stabilizers compared to other yogurts.
- **Greek-style/ strained, concentrated yogurt** – A style of yogurt obtained by straining or centrifuging plain yogurt. It consists of a cream cheese like texture and a higher protein content.

- **Frozen yogurt** – Typically contains 10%-15% plain yogurt blended with an ice cream mix. The product can come in soft and hard frozen varieties and is served as a low-fat or nonfat product.
- **Yogurt drinks/smoothies** – Yogurt product with a beverage-like consistency that is consumed as a drink or shake.

2.5.2 Yogurt production

Depending on production goals, a programed pasteurization time and temperature is utilized to inactivate bacteriophages and vegetative bacterial cells while improving the growth of starter bacteria. This range also encourages interaction between whey protein and κ-casein and increases the water-binding capacity of the protein system (Hui and Evranuz 2012). Homogenization of a pasteurized yogurt occurs in two stages: the first stage is at 10-20MPa and the second at 3.5MPa. This process reduces the size of fat globule and improves the gel strength during fermentation because of the many protein-protein interactions (Bylund 2003). Inoculating yogurt mixes depends on the quantity of yogurt produced. For small yogurt quantities, or 20-100 gallons, mixes are inoculated with bacterial cultures at a rate of 0.5% - 6% and incubated at 43°C-45°C until the desired pH of 4.4 – 4.6 is reached (Hui and Evranuz 2012). During incubation, the yogurt mix undergoes a homolactic fermentation. This involves the primary starter cultures of *L. delbrueckii* subsp. *bulgaricus* and *S. thermophilus* undergoing glucose metabolism followed by the Embden-Meyerhof pathway. In the simplest of terms, the lactose present in the yogurt mix will be translocated into the starter culture microbiota, hydrolyzed by β-galactosidase into glucose and galactose products; the glucose will be utilized by the cultures while the galactose will be excreted from the cells (Vedamuthu 2006).

2.5.3 Health benefits

The health benefits that come from yogurt are a result of the Lactic acid bacteria (LAB) used to create it. Typically, these bacteria include *L. delbrueckii* subsp. *bulgaricus, L. acidophilus,* and *Streptococcus thermophilus* (Pelczar 1986). LAB bacteria inhibit pathogens through the production of acetic acid, lactic acid and bacteriocins (De Simone and others 1986) and also stabilize the intestinal microflora in combination with antibiotics (Brown and others 2005). Current research involving these bacteria is focused on their ability in yogurt to enhance the gastrointestinal function of mineral absorption and to reduce lactose intolerance by consuming various concentrations of *L. acidophilus* cultured yogurt (Martini and others 1991; Vesa and others 2000). Yogurt, as a fermented dairy product, has been shown to reduce symptoms of various disease states, including colitis, constipation, diarrhea, gastric acidity, gastroenteritis, indigestion, intoxication (bacterial toxins), diabetes, hypercholesterolemia, kidney and bladder disorders, lactose intolerance, liver and bile disorders, obesity, skin disorders and tuberculosis (Hui and Evranuz 2012; White and others 2008).

2.5.4 Strained Yogurt

Concentrated yogurt, also known as labneh in the Middle East, strained yogurt in Europe, and Greek-style yogurt in the United States, is a semi-solid fermented milk product that is derived from yogurt; it is developed by draining away a portion of yogurt's water and water-soluble components (Özer 2006). Concentrated yogurts typically contain 23-25% total solids and 10% fat content and are characterized by a white color, a soft and creamy body, and a slightly acidic flavor (Bylund 2003). This product can be produced with many types of milk, such as cow, goat, and sheep milk.

Concentrated yogurt is also traditionally produced with the cloth bag method, where a full fat yogurt product is strained in a cloth bag until the desired level of total solids is achieved. Due to the slow and labor intensive production of the cloth bag method, factory-scale operations will incorporate the use of other techniques to generate large quantities of concentrated yogurt, including centrifugation, recombination technology, and ultrafiltration (Tamime and Robinson 2007). Due to the low fat and higher protein composition, concentrated yogurt has been growing in popularity in order to improve the diets and health of many consumers.

Chapter 3

The Physico-chemical, Textural, & Rheological Impact of Strained Yogurt in Frozen Yogurt

3.1 Introduction

Greek-yogurt, or concentrated yogurt, is a popular product that can improve the diets and health of many consumers. Due to the product's composition of low fat, higher protein, lactic acid bacteria (LAB), prebiotics and low sweetness, it can be considered as a hub of functional ingredients that consumers can indulge in to meet their nutrition based goals (Hui and Evranuz 2012; Özer 2006). However, despite its health benefits, Greek-yogurt may put off certain consumers due to its increased tartness and reduced sweetness; this may result in consumers purchasing this stye of yogurt with added amenities (e.g., fruit toppings and indulgent snacks) that may detract from the initial health benefits of the original product (Meyer and others 2012; Nachay 2014). Utilizing the product of Greek-yogurt itself as a functional ingredient in frozen desserts can provide a unique opportunity to deliver a healthy product in a more palatable package. With the increase in consumption of clean label foods formulated with natural ingredients (McClements and Gumus 2016), this ingredient falls in line with consumer trends. This study aims to assess the physical changes of that incorporation through various physical aspects, including: physico-chemical, textural and rheological measurements.

Ice cream is defined as a dairy foam that contains a mixture of air, water, milk fat, nonfat milk solids, sweeteners, stabilizers, emulsifiers, and flavors (E and others 2010). An average ice cream contains fat, 12%; milk solids non-fat, 11%; sugar, 15%; stabilizer

and emulsifier, 0.3%; and total solids, 38.3% (Arbuckle 1986). On the other hand, a typical composition of nonfat frozen yogurt will contain 0% fat, 13% milk solids non-fat, 13% sucrose, 6% corn syrup solids 36 dextrose equivalent (DE), 2% maltodextrin DE, and 1.2% stabilizers. The final pH will vary between 5.5 and 6.0 depending on the consumer's acceptance. (White and others 2008). According Inoue and others (1998), the optimal pH of frozen yogurts that demonstrated the most desirable flavor and texture was found to be 5.5, in comparison to similar frozen desserts at pH's of 4.5, 5.0 and 6.5. According to Ordonez and others (2000), the target titratable acidity of frozen yogurts is approximately 0.30. Greek yogurts typically contain 23-25% total solids and 10% fat content and are characterized by a white color, a soft and creamy body, and a slightly acidic flavor (Bylund 2003). The (LAB) used in the culture to cultivate Greek-yogurt (e.g. *Lb. delbrueckii* subsp. *bulgaricus, L. acidophilus,* and *Streptococcus thermophilus*) also contribute to consumers health by reducing lactose intolerance (Martini and others 1991; Vesa and others 2000) and inhibiting pathogens through the production of acetic acid, lactic acid and bacteriocins (De Simone and others 1986).

Foods can be analyzed with a variety of physical methods to explain their various properties. In regard to frozen desserts, a wide range of methodologies are used to assess the quality of the product. A proximate analysis can be conducted to assess the crude quantity of macro- and micronutrients with methods from the Official Analytical Chemists, International (AOAC). A texture profile analysis (TPA) can be used to determine the textural properties of various foods, pharmaceuticals, and gels to provide insight into how samples will behave during consumption (Texture Technologies Corp 2020). Rheology is the study of the flow of matter in a liquid or gas state that can provide

information regarding viscosity of solutions, their particle size, distribution, and their flow behavior in relation to a given shear rate (Peleg 2017). An example of these properties can be explained through the rapid melting of frozen dessert products; this is typically an indicator of a low quality product (e.g. low solids content, high overrun and small particles) that can be easily affected by a heat shock event as described by Marshall and others (2003).

The majority of research has focused on changing the formulation of frozen yogurts with different ingredients, such as fibers or proteins (El-Nagar and others 2002; Frank 2014; Isik and others 2011; Soukoulis and others 2008), various fat emulsions (Alfaifi and Stathopoulos 2010; Alfaro and others 2015), probiotics survival (Muzammil and others 2015; Rezaei and others 2014) and microstructure effects from equipment adjustments (Warren and Hartel 2018). To date, no published work has demonstrated the functional advantage of utilizing Greek-yogurt in the manufacturing of frozen desserts. The goal of this study was to compare the physico-chemical, rheological, & textural properties of frozen desserts formulated with Greek-yogurt to common frozen desserts found in the marketplace. These findings will help in understanding how the addition of Greek yogurt to frozen dessert products will significantly affect their functional properties.

3.2 Materials & methods

3.2.1 Materials

A fat-free ice cream mix (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL) was used in the study. Set yogurt and Greek yogurt was created with Prairie Farms fat free skim milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL) and

Yogourmet freeze-dried yogurt starter (Yogourmet, Canada). The starter culture contains skim milk powder, sucrose, and active bacterial cultures (*L. bulgaricus, S. thermophilus, L. acidophilus*).

3.2.1.1 Preparation of yogurt

To produce the set yogurt, skim milk was heated to 80 ºC for 25 seconds, and then cooled to 40 ºC and inoculated with the starter culture (Yogourmet, Canada) which contains 1 billion CFU/gram (Frank 2014). This solution was allowed to ferment to a pH of 4.6 (approx. 4 hours). The yogurt was chilled overnight to set the yogurt.

3.2.1.2 Preparation of Strained (Greek) Yogurt

Greek Style yogurt was prepared according to the method by Aloglu and Seckin (Şanlıdere Aloğlu and Öner 2013; Seckin and Ozkilinc 2011). The straining time of strained yogurt was reduced to approximately 5.5 hours to improve production.

3.2.1.3 Standard Compounds

Phenolphtalein solution (Lot# 121143) was obtained from Fisher Scientific and Sodium Hydroxide 0.1 Standard Solution (Lot# B00U2502) was purchased from Acros Organics.

3.2.2 Methods

3.2.2.1 Frozen Dessert Manufacture

Frozen yogurt treatments were prepared according to the method by Li and others (1997). According to Marshall and others (2003), at least 5% of the weight of the total mix should be yogurt. We used six frozen dessert treatments: three frozen yogurts containing 10, 15, and 20% added set yogurt, and three frozen yogurts containing 10, 15,

and 20% added Greek Style yogurt. Frozen yogurt mixes were prepared in 2.5-gallon batches. Yogurts were manually stirred with their respective ice cream mixes prior to freezing using a stainless-steel spiral mixer (Warner, China) in order to breakdown the gels formed during incubation for three minutes. Table 3-1 describes the specific formulation of each product. A small portion (approximately 15 ml) of each treatment was allocated for rheology and particle size measurements. The remaining stirred frozen yogurt mixes with a semi-liquid consistency were frozen in an ice cream freezing machine (Taylor 0702, Taylor Co. Rockton, IL) in 2.5-gallon batches for approximately 10-20 minutes depending on the treatment. The frozen yogurt batches were packed into and tightly sealed in two-ounce portion cups (Eco-Products, Boulder, CO). Containers were labeled and then placed in a freezer at -40 °C for hardening and storage.

3.2.2.2 Overrun & Melting Rate

The melting rate was measured according to an adjusted method by Pon and others (2015). Frozen yogurt was allowed to temper overnight in a -20ºC freezer before testing. Approximately 30 grams of frozen yogurt were weighed and placed on a wire screen (36/cm2) above a pre-weighed cup and scale. The cup collected the melted frozen yogurt at (25 ± 1°C). The amount of melted frozen yogurt was weighed every 5 minutes to determine the melt rate.

Overrun was measured according to the method by Marshall and others (2003) and Daw and Hartel (2015); Measurements were based on the weights of a specific volume of frozen dessert mix and the respective frozen product. Overrun was calculated using the following equation:

$$Overrun = \frac{(Weight\ of\ Mix - Weight\ of\ the\ same\ vol.of\ Frozen\ Dessert)}{(Weight\ of\ the\ same\ vol.of\ Frozen\ Dessert)}\ X\ 100$$

All treatments were performed in triplicate.

3.2.2.3 pH & Titratable Acidity

One gram sample was weighed and then diluted to 100 ml with distilled water. The pH was then measured for all samples with a calibrated pH meter (Frank 2014). Titratable acidity was evaluated by titration with 0.1 N NaOH, until the phenolphthalein end point was reached and this was conveyed as a percent lactic acid (%TA). All treatments were performed in triplicate. Titratable acidity was calculated using the following equation:

$$\%\ TA = \frac{(ml\ NaOH\ x\ N\ NAOH\ x\ milliequivelant\ weight\ of\ lactic\ acid\ )}{(Weight\ or\ volume\ of\ sample\ in\ grams\ or\ milliliters)}\ X\ 100$$

*The milliequivalent weight of lactic acid is 90/1000 or 0.09.

3.2.2.4 Proximate Analysis

Standard methods of the Association of Official Analytical Chemists were used to determine the moisture, crude protein, crude fat, total ash, crude fiber, and carbohydrate contents of each sample. Moisture content was determined by heating 4.0g of each fresh sample to a constant weight in a crucible placed in an oven maintained at 105 °C (AOAC Official Method 934.01 2006). Crude protein (% total nitrogen x 6.25) was determined by the Kjeldahl method, using 4.0g samples (AOAC Official Method 984.13 (A-D) 2006). Crude fat was obtained by exhaustively extracting 4.0g of each sample in a Soxhlet apparatus using petroleum ether (boiling point range 40-60°C) as the extractant (Folch and others 1957). Ash was determined by the incineration of 4.0g samples placed in a muffle furnace maintained at 550°C for 5h (AOAC Official Method 942.05 2006). Crude

fiber was obtained by digesting two, 4.0g of samples with H_2SO_4 and NaOH and incinerating the residue in a muffle furnace maintained at 550°C for 5h (AOAC Official Method 978.10 2006). Carbohydrate content was determined by the difference of the total weight of a sample from the calculated moisture, crude protein, crude fat, total ash and crude fiber (FAO Food And Nutrition Paper 77 2003). The dry matter was used in the determination of the other parameters. Each analysis was carried out in triplicate.

3.2.2.5 Instrumental Texture Profile Analysis

Texture profile analysis (TPA) was performed with a modified method from Im (1995), Frank (2014) and MacDonald (2018). The test was conducted utilizing a TX-HDi analyzer (TA-HDi, Texture Technologies Corp., Scarsdale, N.Y., U.S.A.) equipped with a 100 kg load cell and a TA-4 cylindrical probe (38 mm diameter; 20 mm height). The test consisted of the probe traveling 15 mm into the center of the ice cream container at a pre-test speed, test speed and post-test speed of 3.0 mm/second with the surface detection feature set to 20 grams of force. Samples were prepared by filling frozen desserts into 60 ml serving cups and were covered with aluminum foil after the frozen product was leveled to the container rim without compaction. After 24 hours of storage at -20ºC, the samples were analyzed with a double compression method and were tested within 30 seconds of removal from the freezer; the temperature of each sample was recorded before testing and the probe was soaked in ice cold water before and between each measurement. The hardness of each sample was determined by the first peak compression force (N) during the penetration. Cohesiveness, springiness, gumminess, chewiness and resilience were calculated based on the gathered TPA plots and suggested equations from

the Texture Technologies Corporation (Texture Technologies Corp 2020). Each analysis was carried out in triplicate.

3.2.2.6 Particle Size and Measurement of Emulsion

Particle size distribution of samples were determined with a Mastersizer 3000 (Malvern Instruments Ltd., Worcestershire, UK). Samples were measured using the refractive indexes of 1.1 and 1.33 for oil and water, respectively at 25°C. The pre-frozen samples were diluted in a 1:10000 ratio with distilled water during the measurement. The particle size was reported as the mean particle diameter d_{43} All measurements were carried out in triplicate.

3.2.2.7 Rheological Properties Measurement

Rheological properties of the pre-frozen samples were determined with a Kinexus Pro Rheometer (Malvern Instruments Ltd., Worcestershire, UK) equipped with a cone (40-mm diameter, 4° angle) and plate geometry. The base of each sample was loaded on a lower plate and the upper cone geometry was gently lowered to a gap of 0.15 mm. A solvent trap setting was used to prevent evaporation. Flow behavior of the sample was conducted under a shear rate ramp from 0.1 s^{-1} to 500 s^{-1} at 25°C. Flow behavior index and consistency coefficient were calculated using the Power Law model. Each treatment was measured in triplicate.

3.3 Experimental design and data analysis

A completely randomized design was utilized to assess differences amongst samples; Orthogonal contrasts and polynomial contrasts were created to determine the significance of yogurt type, yogurt concentration, and the interaction between these factors and their effect on the mean value of each method. The R statistical software

program was used to analyze significant differences ($p < 0.05$) between treatments by one-way ANOVA with all methods. The comparisons between the mean values were evaluated by the Tukey HSD test with most methods. The comparisons between the mean values generated from the proximate analysis were evaluated by the Fisher LSD method. More detailed ANOVA tables of each attribute can be found in Appendix A.

Table 3-1 Frozen dessert formulations per 100g basis for products containing various yogurt types

Ingredients / Sample	Ice Cream Mix[a]	Set Yogurt[b]	Greek Yogurt[c]
Control (No yogurt added)	100	0	0
FYA (90% Ice cream mix; 10% set yogurt)	90	10	0
FYB (85% Ice cream mix; 15% set yogurt)	85	15	0
FYC (80% Ice cream mix; 20% set yogurt)	80	20	0
GFYA (90% Ice cream mix; 10% Greek yogurt)	90	0	10
GFYB (85% Ice cream mix; 15% Greek yogurt)	85	0	15
GFYC (80% Ice cream mix; 20% Greek yogurt)	80	0	20

[a] Fat-free ice cream mix (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

[b] Developed with fat-free milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

[c] Developed with fat-free milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

3.4 Results & discussion

3.4.1 Overrun and melting rate

The overrun, or the increase in volume of ice cream over the volume of mix used, is caused by the incorporation of air that is dispersed through the fat-in-serum emulsion; the interface between the water and air is stabilized by a film of unfrozen material (Goff and Hartel 2013). In this study, yogurt concentration and yogurt type were shown to have highly significant linear interaction effect ($P<0.001$) on the average overrun among the treatments. As the only significant difference, the control treatment (mean= 30.822%) had a higher overrun compared to GFYC (mean= 26.271%), the sample with the highest concentration of Greek yogurt (Table 3-2). According to Marshall and others (2003), the super-premium ice cream overrun range is 20-40%; under these conditions, all samples developed in this study fall within the range of a desired overrun (Figure 3-1). The lower overrun percentage found within GFYC could be attributed to the decrease in pH similar to results from Guner and others (2007). Alfaifi and Stathopoulos (2010) demonstrated an increased overrun content with an increase in whey protein concentrate.

The frozen desserts in this study demonstrated significant melting rate differences among the samples, indicating highly significant main effects among yogurt type ($P<0.001$) and yogurt concentration ($P<0.001$) on the average melting rate among the treatments. The model demonstrates a decrease in the average melting rate among the treatments as different yogurts and higher concentrations of those yogurt were applied into them. This effect is noticeable among the yogurt types as treatments with Greek-yogurt demonstrated a drastically lower melting rate compared to treatments with set-yogurt. The control treatment had the significantly highest melting rate of 2.233% melted

sample/ minute compared to all other treatments besides FYA; FYA and GFYA had significantly higher melting rates in comparison to treatments containing higher concentrations of yogurt, including FYC, GFYB and GFYC (Table 3-2).

Overrun and the air cell structure of the ice cream product are the main factors that influence the melting of rate, rheological properties, and shape retention of the frozen dessert matrix (Bahramparvar and Mazaheri Tehrani 2011). Typically, increasing the fat concentration of frozen desserts decreases their coldness, ice crystals, and melting rate properties (Stampanoni Koeferli and others 1996). However, the result of this study goes against Stampanoni's research, as the decreasing melting rates among the treatments follows a trend of decreasing in fat concentration. Instead, the results are similar to work from Favaro-Trindade and others (2007) as they found frozen dessert samples with lower pH values or 4.5 demonstrated lower melting rates. They believed this increased resistance to heat might be related to how the pH greatly influences protein structure. The proteins present in the lower pH mixes may have denatured, allowing for the development of long structured protein aggregates; this would make it more difficult for the matrix pass through the screen. Low protein concentration that have been collected from slower melting frozen desserts demonstrate that structural protein changes within the samples could have changed irreversibly, hindering the proteins passing through the screen (Tharp and others 1998). The results in this study demonstrated that increasing the yogurt concentration in a frozen dessert mix will decrease the melting rate of the resulting product (Figure 3-2).

Table 3-2 Mean values of overrun % and melting rate of seven frozen desserts various concentrations of yogurt and Greek yogurt

Sample	Overrun %*	Melting Rate* (Percentage Melted Per Minute after 30 minutes)
CTRL	30.822±2.493[a]	2.233±0.474[a]
FYA	29.559±1.002[ab]	1.598±0.796[ab]
FYB	33.167±1.974[a]	0.650±0.322[cd]
FYC	32.675±2.14[a]	0.265±0.130[d]
GFYA	30.307±3.089[a]	1.127±0.475[bc]
GFYB	33.049±2.085[a]	0.225±0.090[d]
GFYC	26.271±1.821[b]	0.243±0.107[d]

There are no significant differences at $p<0.05$ among the samples with the same superscript letter.
*units are in (mean value ± SD)

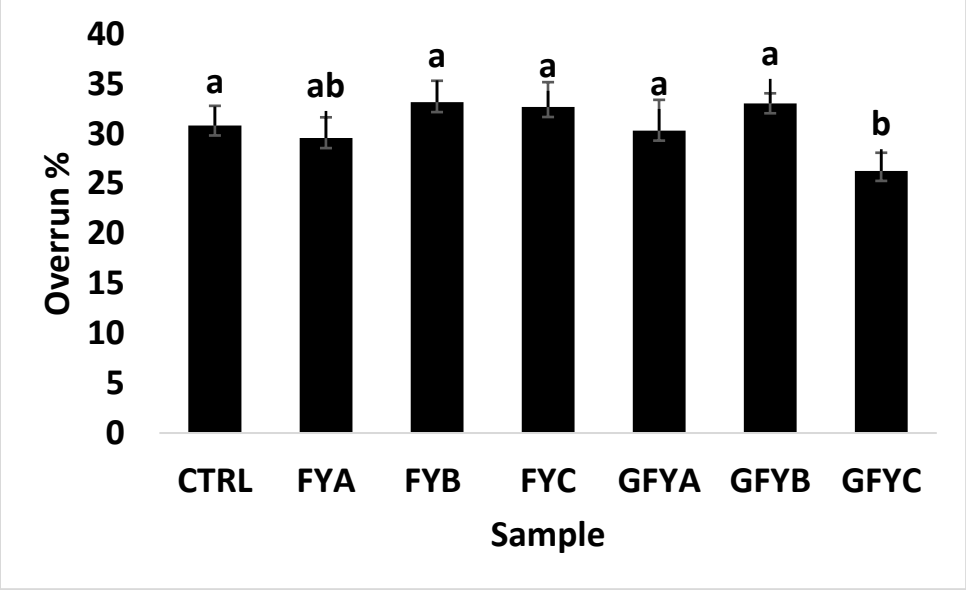


Figure 3-1 Mean values for Overrun % of experimental frozen desserts of seven frozen desserts with various concentrations of yogurt and Greek

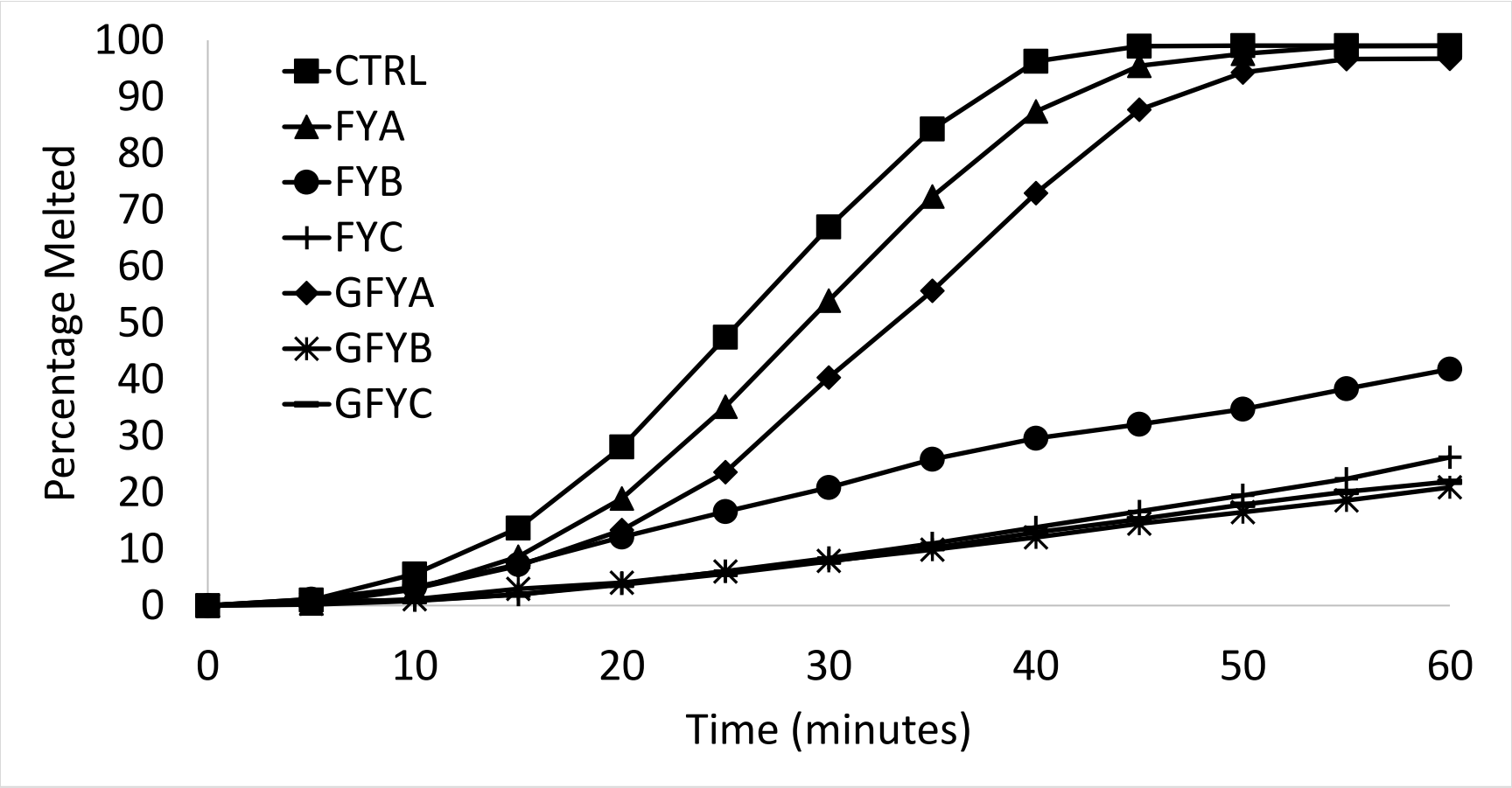


Figure 3-2 **Melting curves of experimental frozen desserts of seven frozen desserts with various concentrations of yogurt and Greek yogurt**

3.4.2 pH & titratable acidity

The frozen desserts in this study demonstrated significant differences in pH ($P<0.001$) and titratable acidity ($P<0.001$). Yogurt concentration and type were shown to have highly significant linear ($P<0.05$) and quadratic ($P<0.05$) interaction effects on the average pH among the treatments. They demonstrate that there is a decrease in the average pH among the treatments as different yogurts and higher concentrations of those yogurt were applied into them. Greek-yogurt decreased the pH of frozen dessert formulations at a greater level compared to set-yogurt. The control treatment had the significantly highest pH of 6.54 compared to all other samples; FYA demonstrated significantly higher pH than all other treatments except for the control ice cream (Table 3-3).

Yogurt concentration and type were shown to have a highly significant linear ($P<0.001$) and quadratic ($P<0.001$) interaction effects on the average titratable acidity among the treatments. The model demonstrated an increase in the average titratable acidity among the treatments as different yogurts and higher concentrations of those yogurt were applied into them. The control treatment had the significantly lowest titratable acidity of 0.345 compared to all other treatments; treatments with set yogurt demonstrated significantly lower titratable acidity than treatments with Greek-yogurt (Table 3-3). The results of this method fall in line with similar pH and titratable acidity values found in Inoue and others (1998), Guner and others (2007) and Frank (2014). The interaction of yogurt concentration and type can be seen at the 20% addition yogurt level. Despite FYC and GFYC having a similar volume of yogurt added, the differences in yogurt type caused a noticeable increase in titratable acidity and decrease in pH. This

could be attributed to the high titratable acidity and low pH of the initial yogurt ingredients that were developed.

Table 3-3 Mean values of Ph and Titratable Acidity of seven frozen desserts with various concentrations of yogurt and Greek yogurt

Sample	pH*	%Titratable Acidity*	Ingredients	pH*	%Titratable Acidity*
CTRL	6.54±0.087[a]	0.345±0.018[a]	Milk	6.777±0.010	0.173±0.018
FYA	5.54±0.113[b]	0.531±0.005[b]	Yogurt	4.365±0.028	0.793±0.024
FYB	5.12±0.091[c]	0.556±0.040[b]	Greek Yogurt	3.717±0.048	1.426±0.024
FYC	4.87±0.043[d]	0.556±0.041[b]			
GFYA	5.10±0.053[c]	0.647±0.037[c]			
GFYB	4.73±0.105[d]	0.694±0.018[c]			
GFYC	4.27±0.026[e]	1.005±0.044[d]			

There are no significant differences at $p<0.05$ among the samples with the same superscript letter.
* Units are in ((g/100g) ± SD)

3.4.3 Proximate analysis

The results from the proximate analysis indicated a mixture of results (Table 3-4). The frozen desserts in this study demonstrated significant differences in fiber content ($P<0.05$), indicating a highly significant linear ($P<0.05$) and quadratic ($P<0.01$) interaction effects on the average fiber concentration among the treatments. Although there were differences among treatments based on yogurt type, the FYC treatment had the significantly highest average fiber content of 0.057g/ 100g of sample compared to GFYC. There were no significant differences in the ANOVA models for protein, moisture, fat, ash, and carbohydrate content among the different treatments. However, there were significant differences among the treatments regarding fat and protein concentrations. A decreasing trend in fat concentration and increasing trend in protein concentration was found as different yogurts and higher concentrations of those yogurt were applied into a frozen dessert formulation. The control treatment demonstrated a higher concentration of fat compared to all other treatments. The treatment with the highest concentration of Greek yogurt – GFYC – demonstrated a significantly higher concentration of protein compared to other treatments.

Table 3-4 Average Proximate analysis values of seven frozen desserts with various concentrations of yogurt and Greek yogurt*

Sample	Protein	Moisture	Fat	Fiber	Ash	Carbohydrates
CTRL	2.800±0.615^{b}	64.120±4.534^{a}	9.363±2.281^{a}	0.023±0.006^{c}	0.833±0.094^{a}	22.883±3.257^{a}
FYA	3.097±0.508^{b}	69.653±4.619^{a}	6.083±1.586^{b}	0.033±0.015^{bc}	0.837±0.077^{a}	20.330±3.626^{a}
FYB	3.070±0.462^{b}	70.687±4.710^{a}	4.776±2.249^{b}	0.027±0.006^{c}	0.820±0.051^{a}	20.647±2.967^{a}
FYC	3.243±0.732^{ab}	70.693±3.147^{a}	5.617±0.587^{b}	0.057±0.021^{a}	0.867±0.140^{a}	19.580±3.921^{a}
GFYA	3.753±0.656^{ab}	68.317±3.064^{a}	5.973±0.990^{b}	0.037±0.015^{abc}	0.877±0.119^{a}	21.080±3.110^{a}
GFYB	3.660±0.530^{ab}	70.120±4.653^{a}	5.053±1.711^{b}	0.053±0.015^{ab}	0.830±0.075^{a}	20.336±3.749^{a}
GFYC	4.167±0.623^{a}	70.270±3.234^{a}	4.427±1.911^{b}	0.020±0.000^{c}	0.850±0.125^{a}	20.287±1.445^{a}

There are no significant differences at $p<0.05$ among the samples with the same superscript letter.

*Units are in ((g/100g of sample) ± SD)

3.4.4 Instrumental texture profile analysis

Texture analysis was conducted on all treatments to measure the hardness, cohesiveness, springiness, gumminess, chewiness, and resilience of the experimental treatments. The texture profile analysis indicated a mixture of results (Table 3-5). The frozen desserts in this study demonstrated significant differences in hardness ($P<0.001$), gumminess ($P<0.01$), and chewiness ($P<0.01$) and a highly significant yogurt type effect ($P<0.001$) on the respective attributes among the treatments. These results demonstrate an increase in the average hardness among the treatments as different yogurts were applied into them. Treatments containing Greek-Yogurt had a higher impact on these attributes compared to treatments containing set-yogurt. The control treatment had a significantly lower hardness, gumminess and chewiness – 265g, 44.9 and 23.6 respectively – compared to the GFYC treatment (Table 3-5).

There were no significant differences in the ANOVA models for cohesiveness, resilience, and springiness among the different treatments, resulting in the different types of yogurts and concentrations having no effect on these attributes (Table 3-5). The results from this study are similar to work from Abd El-Rahman and others (1997) and Alfaro and others (2015) that demonstrate no significant differences in hardness due to changes in fat concentration within frozen desserts. This is study is also similar to Geilman and Schmidt (1992) and Nixon (2012) that demonstrate increasing the protein content in frozen desserts increases the hardness attribute of their respective treatments.

Table 3-5 Texture Profile Analysis mean values derived from seven frozen desserts various with concentrations of yogurt and Greek yogurt

Sample	Hardness (g ± SD)	Cohesiveness (% ± SD)	Springiness (% ± SD)	Gumminess (mean ± SD)	Chewiness (mean ± SD)	Resilience (% ± SD)
CTRL	265±44.8^{c}	0.161±0.103^{a}	0.399±0.216^{a}	44.9±33.9^{b}	23.6±23.7^{b}	0.106±0.103^{a}
FYA	321±61.3^{bc}	0.118±0.017^{a}	0.418±0.043^{a}	38.3±11.8^{b}	16.3±6.7^{b}	0.139±0.017^{a}
FYB	169±62.8^{c}	0.149±0.051^{a}	0.369±0.093^{a}	23.1±5.72^{b}	8.87±4.09^{b}	0.115±0.051^{a}
FYC	283±41.3^{bc}	0.139±0.058^{a}	0.378±0.067^{a}	40.0±20.1^{b}	15.8±10.2^{b}	0.119±0.205^{a}
GFYA	579±14.1^{b}	0.188±0.063^{a}	0.551±0.117^{a}	108.0±39^{ab}	62.2±29.7^{ab}	0.115±0.021^{a}
GFYB	578±28.6^{b}	0.163±0.048^{a}	0.505±0.134^{a}	98.7±67.8^{ab}	54.6±48.7^{ab}	0.112±0.025^{a}
GFYC	1215±18.60^{a}	0.211±0.148^{a}	0.497±0.172^{a}	275.3±20.9^{a}	162.9±14.3^{a}	0.464±0.509^{a}

There are no significant differences at $p<0.05$ among the samples with the same superscript letter.

3.4.5 Particle size and emulsion

There were significant particle size differences ($P<0.001$) among the mean diameter of fat globules within the prepared treatments (Table 3-6). Yogurt concentration and type were shown to have highly significant linear interaction effects ($P<0.001$) and quadratic effects ($P<0.001$) on the average particle size among the treatments. The models demonstrated an increase in the average particle size among the treatments as different yogurts and higher concentrations of those yogurt were applied into them. Treatments containing Greek-yogurt demonstrated a higher particle size compared to set-yogurt. In the absence of any yogurt ingredient, the mean diameter of particles within the control treatment significantly smaller. Generally, both types of frozen yogurt samples (including set and Greek yogurt) reflected very similar trends. With the addition of yogurt to the ice cream mix, an increase in the $D[4,3]$ was observed to above ~10 μm for frozen yogurts and above ~18 μm for frozen yogurts with Greek yogurt. Most treatments demonstrated significant differences from one another. This was likely due to the aggregation of the protein-stabilized fat globules as a result of the lowered pH in the mix after adding the various yogurts close to a value of pH 5 (Favaro-Trindade and others 2007). Since the fat content among all frozen yogurt treatments are not different, differences in particle size could be attributed to various types of protein aggregates formed due to denaturation of milk proteins in yogurt (e.g., casein/whey interactions), high-density emulsion complexes between fat and casein during the manufacturing of treatments, residual large yogurt gel globules, and normal homogenized fat globules (Tamime and Robinson 2007).

It should be noted that the control treatment mix was an emulsion prepared at approximately pH 6.5 exhibited a unimodal distribution with the smallest mean particle size (Figure 3-3), suggesting that the emulsion was homogenous with similar particle sizes (McClements and others 2007). All frozen dessert treatments formed with any type of yogurt demonstrated a bimodal distribution with the major peak centered around 15 µm and the minor peak centered around 1 µm (Figure 3-3). The change in distribution could be attributed to the change in whey protein and casein content from the added set and Greek yogurts, as they have been shown to increase the thickness (Baier and others 2009; Torres and others 2011) and particle size (Krzeminski and others 2011; Levinson and others 2016). This can be seen on the distribution, as the volume of larger particles increases with an increase in yogurt content and a decrease in pH (Lin and others 2018). However, more work needs to be considered to separate and quantify the specific type of proteins found within each treatment to understand which milk protein is contributing a greater impact on each treatment.

Table 3-6 Average particle size (µm) of fat globules and pH of seven frozen desserts with various concentrations of yogurt and Greek yogurt

Sample	Particle Size (µm ± SD))	pH
CTRL	2.284 ± 1.671^{e}	6.54 ± 0.087^{a}
FYA	11.399 ± 2.571^{d}	5.54 ± 0.113^{b}
FYB	12.71 ± 1.097^{cd}	5.12 ± 0.091^{c}
FYC	14.67 ± 0.545^{c}	4.87 ± 0.043^{d}
GFYA	18.922 ± 5.207^{b}	5.10 ± 0.053^{c}
GFYB	23.343 ± 3.136^{a}	4.73 ± 0.105^{d}
GFYC	21.18 ± 6.581^{ab}	4.27 ± 0.026^{e}

There are no significant differences at $p<0.05$ among the samples with the same superscript letter.

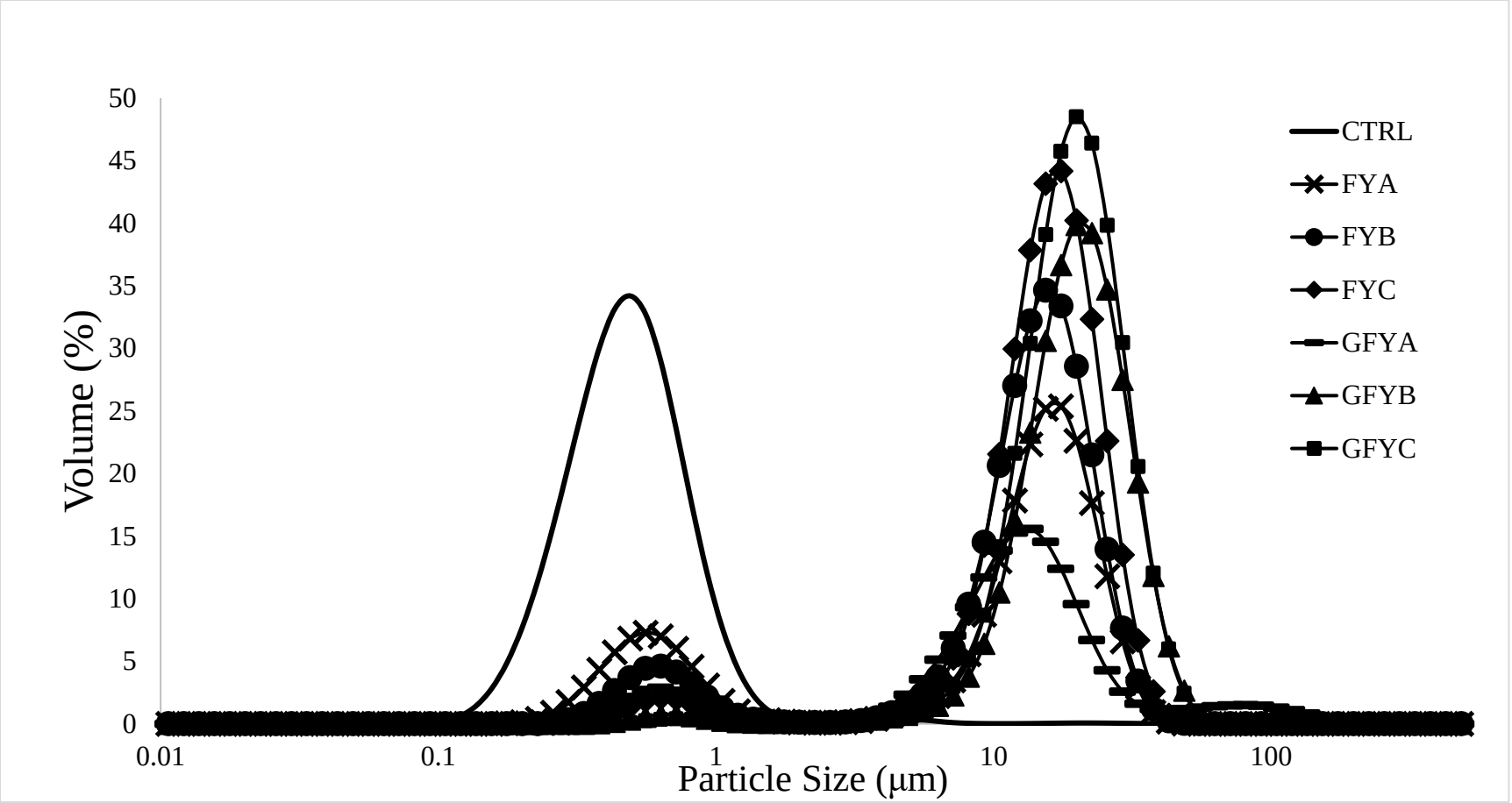


Figure 3-3 Particle size distribution of emulsions from seven frozen desserts mixes with various concentrations of yogurt and Greek yogurt

3.4.6 Rheological properties of frozen desserts

Rheological properties of emulsions were measured immediately after frozen dessert mixes were prepared. Plots of apparent viscosity versus shear rate are shown in Figure 3-4. Rheological properties as described by the consistency coefficient (K) and flow behavior index (n) were determined using the Power Law model (Table 3-7). Significant differences were found among treatments for the K ($P<0.05$) and n ($P<0.05$). There were no deflection points observed among the prepared treatments. The flow behavior of emulsions developed with various yogurts ranged from 0.286 to 0.636, suggesting a shear-thinning behavior ($n < 1$) (Huan and others 2016; Kotchabhakdi 2018). Yogurt concentration ($P<0.05$) and type ($P<0.05$) were shown to have an impact on the average consistency coefficient and flow behavior index among the treatments. The results indicated that an increase in the average K and a decrease in the average n among the treatments as different yogurts and higher concentrations of those yogurt were applied into them. The flow behavior of treatments with Greek yogurt tended to have a higher consistency coefficient compared to samples with set yogurt. In other words, frozen dessert mixes with Greek yogurt demonstrated a higher viscosity that is reflective of its larger particle sizes, bridging and flocculation compared to other treatments. The increase in viscosity for these treatments could be attributed to the increase in casein micelle content similar to work from Alvarez and others (2005). The addition of yogurt to the control base had the opposite of effect, decreasing the overall viscosity of the matrix despite its increasing particle size. This is similar to results from Soukoulis and others (2007), as they found the addition of whey protein reduced the viscosity of mixes.

Table 3-7 Power Law model parameters of frozen dessert samples with various concentrations of yogurt and Greek yogurt

Sample*	K ($Pa \cdot s^n$)	n
CTRL	0.322 ± 0.314^{ab}	0.561 ± 0.075^{ab}
FYA	0.337 ± 0.245^{ab}	0.506 ± 0.113^{ab}
FYB	0.196 ± 0.206^{a}	0.629 ± 0.095^{a}
FYC	0.174 ± 0.155^{a}	0.636 ± 0.081^{a}
GFYA	0.702 ± 0.681^{ab}	0.499 ± 0.131^{ab}
GFYB	0.957 ± 0.841^{ab}	0.453 ± 0.138^{ab}
GFYC	1.651 ± 0.568^{b}	0.286 ± 0.048^{b}

K = consistency index and n = flow behavior index was determined by fitting the flow curve to the Power Law model.
There are no significant differences at $p<0.05$ among the samples with the same superscript letter.

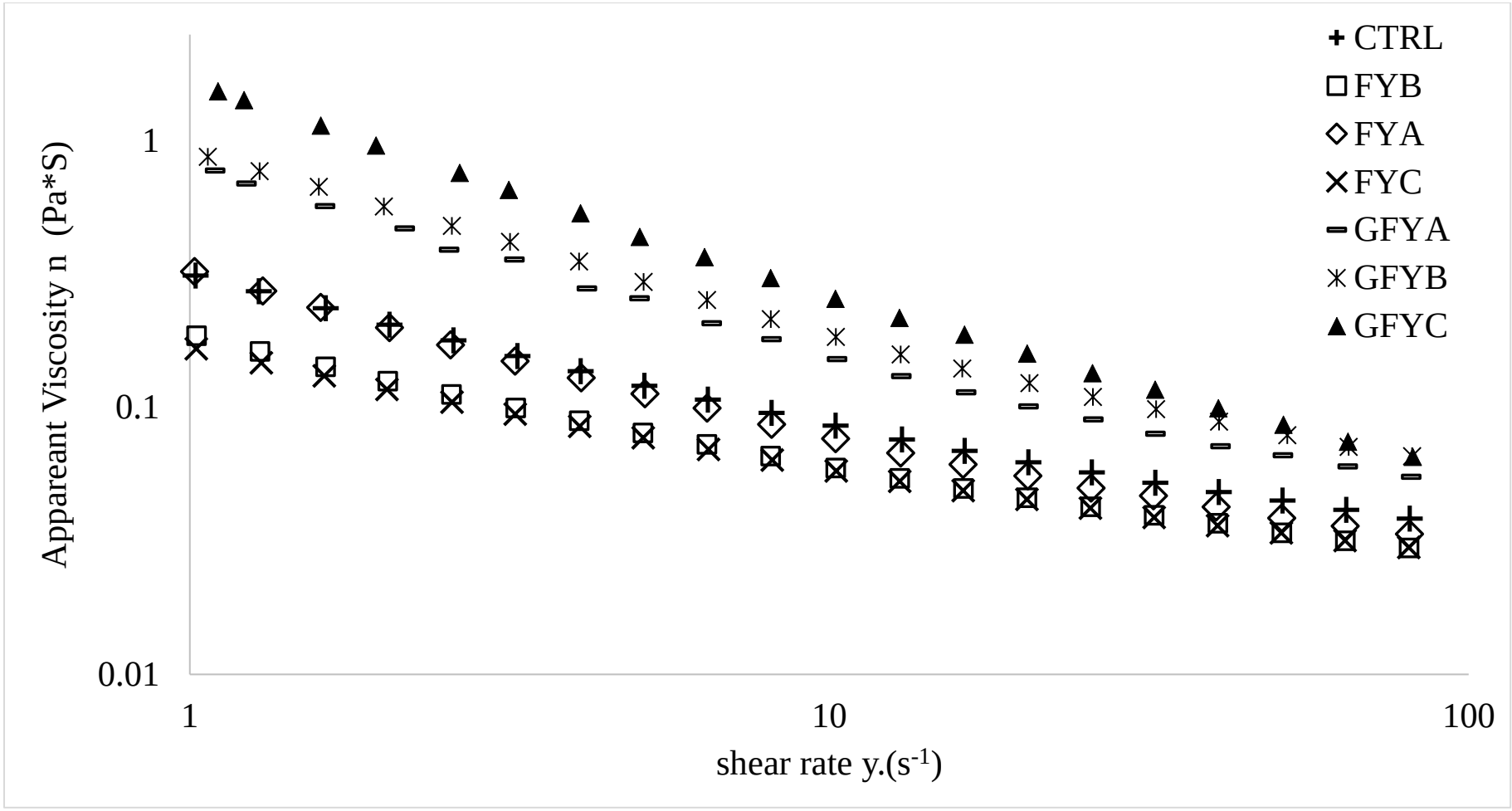


Figure 3-4 Apparent viscosity of fresh frozen desserts mixes with various concentrations of yogurt and Greek yogurt

3.5 Conclusion

The overall goal of this study was to assess the physico-chemical impact of various applying yogurt types and concentrations into a frozen dessert matrix. The various attributes of frozen desserts, such as overrun, melting rate, pH, titratable acidity, proximate analysis, texture profile analysis, particle size and rheological properties, were investigated among frozen desserts containing set yogurt and Greek-style yogurt. Our results clearly indicated that despite the lack of significant differences among macronutrients, significant differences could be observed among pH, titratable acidity, hardness, gumminess, chewiness, particle size and flow behavior at small changes in the frozen dessert formulation. Samples containing higher yogurt concentrations, especially Greek yogurt, demonstrated the highest significance among the attributes.

Chapter 4

Organic Acid and Carbohydrate Analysis of Frozen Desserts Containing Strained Yogurt

4.1 Introduction

Yogurt tends to have a similar organic acid and carbohydrate profile to other fermented dairy products due to the quality of ingredients, flavor development, and their similar metabolic pathways during fermentation (Hui and Evranuz 2012). What separates yogurt from other dairy products is its long list of interchangeable lactic acid bacteria (LAB), their respective proteolytic and lipolytic activities, and the resulting organic acid profile. During yogurt fermentation, LAB hydrolyzes the lactose into glucose and galactose (Costa and others 2013; Hui and Evranuz 2012). Many species of lactic acid bacteria metabolize carbohydrates into trace amounts of acetic acid, formic acid, and ethanol by the homofermentative metabolic pathway (Chramostova and others 2014). Other factors like the origin of the milk, the type of milk heat treatment (e.g. pasteurized or raw milk), and the starter used can also influence the extent of the proteolysis and the resulting compounds, flavor, and texture of the final yogurt product (Zhang and Metzger 2021). Organic aids and carbohydrates are important indicators of bacterial activity in yogurt, contributing to the development of the sensory characteristics taste and flavor of this product (Costa and others 2016). The analysis of these compounds, in conjunction with pH and acidity, could be used to monitor the fermentation process under the influence of various starter cultures and probiotic bacteria (González de Llano and others 1996). It is thus important to develop a precise and reliable method to detect the

quantities of organic acids and carbohydrates to ensure production quality of fermented dairy products.

High-performance liquid chromatography (HPLC) is the most versatile and widespread technique to analyze food components in dairy products (Bevilacqua and Califano 1989; Pereira da Costa and Conte-Junior Carlos 2015; Şanlıdere Aloğlu and Öner 2013; Zhang and Metzger 2021). HPLC systems used in combination with detectors, such as the diode array detector (DAD), re-fractive index (RI), and visible wavelength detector (VWD), can quantify the organic acids and carbohydrates within a food matrix after it has been prepped for analysis (Pereira da Costa and Conte-Junior Carlos 2015). In order for this equipment to be utilized reliably, a method of validation on the given equipment must be performed. The validation of a methodology reduces possible analytical errors to an acceptable level and improves the reliability and reproducibility of the final analysis (Chan and others 2004). Most scientific literature require certain guidelines to consider a method validated, including: selectivity, linearity, precision, limit of detection (LOD), limit of quantification (LOQ), recovery and robustness (Chan and others 2004). Some parameters, such as linearity, focus on the proportionality of the analytical values to their respective concentration. The recovery parameter is also significant as it estimates the yield of an analytical technique that is obtained by fortifying a biological matrix with a known amount of an analyte (Guideline 2005). Given the right set of equipment, one can develop intricate HPLC methodologies that involve multiple detectors to analyze two or more sets of food components (Costa and others 2016). However, the literature provides a variety of methodologies in the analysis of components from dairy products including different method validations and

internal or external standards (Adhikari and others 2002; Lamprecht and Blochberger 2009; Yüksel and others 2017; Zhang and Metzger 2021).

The goal of this study was to develop methods that could extract and precisely and accurately quantify organic acids and carbohydrates from various frozen desserts using an HPLC analysis. These findings will help in understanding how the addition of Greek yogurt to frozen dessert products will affect organic acid and carbohydrate profiles in comparison to similar products.

4.2 Materials & methods

4.2.1 Materials

4.2.1.1 Ingredients for method validation

Nonfat yogurts and Greek-yogurts were purchased from a local grocery store for the method validation of various organic acids and carbohydrates. Both yogurts were manufactured with cultured pasteurized grade-A nonfat milk; However, the set-yogurt contained pectin and *L. acidophilus* while the Greek-yogurt contained *Bifidobacterium, L. acidophilus, L. delbruckii* subsp. *bulgaricus, L. paracasei and S. thermophilus.* The yogurts were combined with milk, pure granulated sugar, heavy whipping cream, and non-fat milk solids purchased from a local grocery store and Palsgaard® ExtruIce 252 Lot# 7172058 (stabilizer/Emulsifier) to develop various frozen desserts for further validation. These included a control ice cream with no yogurt, a frozen yogurt composed of nonfat yogurt (10% nonfat yogurt: 90% ice cream), and a frozen yogurt composed of Greek-yogurt (10% Greek-yogurt: 90% ice cream).

4.2.1.2 Standard Compounds, Mobile Phases, and Solvents

High-purity standard compounds were purchased from several manufacturers (Table 4-1). Two mobile phases were developed for the HPLC analysis of organic acids and carbohydrates. The organic acid mobile phase contained 271 μL of sulfuric acid and 60 mL of acetonitrile made to volume in a 1 L volumetric flask with HPLC water. The carbohydrate mobile phase consisted entirely of HPLC water.

The solvent for standard mixtures (SMS) and sample extraction solvent (ES) consisted of various components depending on the analyte. The SMS for most organic acids and carbohydrates were composed of HPLC water and an internal standard. Succinic acid was used as the internal standard for organic acids and fructose was used as the internal standard for carbohydrates. The uric acid solution was made with 0.1 N NaOH and HPLC-grade water due to its requirement for a basic pH environment for dissolution (Adhikari and others 2002). The ES for organic acids contained 135 μL of Sulfuric acid and one gram of succinic acid made to volume in a 500 mL volumetric flask with HPLC water. The ES for carbohydrates contained 135 μL of sulfuric acid and 2.33 grams of fructose made to volume in a 500 mL volumetric flask with HPLC water.

Table 4-1 Standard Compound and Solvent Information

Chemical Compound & Solvents	Manufacturer	Lot #	Part #	Purity Factor
Acetic Acid, Glacial	Fisher Scientific	131098	A385	99.90%
Acetonitrile (HPLC Plus)	Sigma Aldrich	SHBL0821	A300	≥99.9%
Butyric Acid	Sigma Aldrich	SHBC1023V	B103500	≥99.0%
Citric Acid	Sigma Aldrich	MKBH2288V	W230618	≥99.5%
D - Lactose	Sigma Aldrich	BCBX1234	61345	≥98.0%
DL - Lactic Acid	Sigma Aldrich	BCCB5390	69785	~90.0%
Formic Acid	Fisher Scientific	771790	A-119	90.00%
Fructose	Sigma Aldrich	SLCD6611	F0127	≥99.0%
galactose	Sigma Aldrich	BCCC2355	G0750	≥99.0%
glucose	Sigma Aldrich	50K0238	G-8270	99.50%
Propionic Acid	Sigma Aldrich	064K3651	P1386	99.90%
Pyruvic Acid	Sigma Aldrich	SHBL6258	107360	98.00%
Sodium Hydroxide (0.1 N) Std Solution	Acros Organics	B00U2502	12419	Pure
Succininc Acid	Acros Organics	A0403416	158742500	99.00%
Sucrose	Sigma Aldrich	099K02014	57903	≥99.5%
Sufuric Acid	Fisher Scientific	193876	A300	96.10%
Uric Acid	Sigma Aldrich	BCBW1849	U0881	≥99.0%
Water (HPLC Grade)	Fisher Scientific	20641	W5	Pure

4.2.1.3 Ingredients for Treatments

Fat-free ice cream mix (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL) was used in the study. Set yogurt and Greek yogurt was created with Prairie Farms fat free skim milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL) and Yogourmet freeze-dried yogurt starter (Yogourmet, Canada). The starter culture contained skim milk powder, sucrose, and active bacterial cultures (*L. bulgaricus, S. thermophilus, L. acidophilus*).

4.2.1.3.1 Preparation of yogurt

To produce the set yogurt, Skim milk was heated to 80 ºC for 25 seconds, and then cooled to 40 ºC and inoculated with the starter culture (Yogourmet, Canada) which contains 1 billion CFU/gram (Frank 2014). This solution was allowed to ferment to a pH of 4.6 (approx. 4 hours). The yogurt was chilled overnight to set the yogurt.

4.2.1.3.2 Preparation of Strained (Greek) Yogurt

Greek Style yogurt was prepared according to the method by Aloglu and Seckin (Şanlıdere Aloğlu and Öner 2013; Seckin and Ozkilinc 2011). The straining time of strained yogurt was reduced to approximately 5.5 hours to improve production.

4.2.1.3.3 Frozen Dessert Manufacture

Frozen yogurt treatments were prepared according to the method by Li and others (1997). According to Marshall and others (2003), at least 5% of the weight of the total mix should be yogurt. We used six frozen dessert treatments: three frozen yogurts containing 10, 15, and 20% added set yogurt, and three frozen yogurts containing 10, 15, and 20% added Greek Style yogurt. Frozen yogurt mixes were prepared in 2.5-gallon batches. Yogurts were manually stirred with their respective ice cream mixes prior to

freezing using a stainless-steel spiral mixer (Warner, China) in order to break down the gels formed during incubation for three minutes. Table 3-1 describes the specific formulation of each product. A small portion (approximately 15 ml) of each treatment was allocated for rheology and particle size measurements. The remaining stirred frozen yogurt mixes with a semi-liquid consistency were frozen in an ice cream freezing machine (Taylor 0702, Taylor Co. Rockton, IL) in 2.5-gallon batches for approximately 10-20 minutes depending on the treatment. The frozen yogurt batches were packed into and tightly sealed in two-ounce portion cups (Eco-Products, Boulder, CO). Containers were labeled and then placed in a freezer at -40 °C for hardening and storage.

4.2.1.4 Analytical Equipment

HPLC analysis was performed with a Scientific Systems Lab Alliance III pump (State College, PA), a Varian Prostar 410 autosampler (Walnut Creek, CA), and a Galaxie Chromatography data system (version 1.9.302.530). Organic acids were separated on an HPX-87H Bio-Rad Aminex column (Richmond, CA), using a Bio-Rad cation-H Micro-guard (Richmond, CA), and an Agilent technology 1260 Infinity VWD detector. Carbohydrates were separated on an HPX-87P Bio-Rad Aminex column (Richmond, CA), using a Bio-Rad carbo-P Micro-guard (Richmond, CA), and a Waters 21414 Refractive Index Detector. Although two different columns were used, both columns were 300 mm x 7.8 mm.

4.2.2 Methods

4.2.2.1 HPLC Analytical method

Prepared solutions were placed in 2 mL HPLC autosampler vials and analyzed via HPLC. The mobile phase (section 4.2.1.2), regardless of the type, was purged with high-

purity helium for 15 minutes. The system was then purged of mobile phase already present in the lines for 5 minutes at 1 mL/min to avoid potential issues with gas bubble formation. Inlet frits in the mobile phase containers were also visually checked at this time to be sure that no air bubbles were trapped behind them. After the initial maintenance, the HPLC method was then initiated. Both methods used isocratic separation. For organic acids, a 0.700 mL/min flowrate was maintained at a column temperature of 60 °C containing its respective mobile phase of sulfuric acid, acetonitrile, and HPLC water. All organic acids were quantified at 220nm for a run time of 22 minutes. For carbohydrates, A 0.700 mL/min flowrate was maintained at a column temperature of 85 °C containing its respective mobile phase of HPLC water. Carbohydrate analyses were conducted for 15 minutes for each run. An initial blank was ran at the beginning of each day for each method to assure that separation conditions would be exactly the same for each actual sample injection. Both mobile phases were allowed to run for at least 15 minutes until backpressure was reduced and the detector signal had stabilized. The injection volume was 10 μL for each method and the needle was washed with HPLC water. These methods were modified from Costa and others (2016) and Yüksel and others (2017).

4.2.2.2 Standard Curve Preparation

Stock solutions of all compounds were prepared by quantitatively transferring accurately massed quantities of standard compounds into either single 50ml or 100 mL volumetric flasks and making to volume with their respective SMS (section 4.2.1.2). After stock preparation was complete for each compound, the stock was diluted in SMS to prepare an internal standard curve consisting of approximately 5-6 equidistant

dilutions for each standard compound in respect to an internal standard. The internal standards included succinic acid for organic acids and fructose for carbohydrates. The internal standard curve information for each compound, including pure compound concentrations, internal standard concentrations, and the area counts for both compounds, can be reviewed in are calculated in Appendix C.

Prepared internal standard solutions were placed in a 2 mL HPLC autosampler vials were analyzed with their respective HPLC analytical methods (section 4.2.2.1). Prepared standards were run in order from least concentrated to most concentrated solution for each compound. Standard curves were plotted with known analyte/internal standard concentration ratios on the x-axis and the analyte/internal standard peak areas on the y-axis; The line describing each curve is derived as a mathematical equation allowing for the estimation of the concentration of each compound in each sample. Coefficients of determination (R^2) were also calculated for each curve, with values greater than 0.99 being deemed acceptable

4.2.2.3 Sample Preparation and Extraction Method of Organic Acids

The extraction solvent (ES) for organic acids was prepared on the day of analysis by combining 135 μL of sulfuric acid and one gram of succinic acid made to volume in a 500 mL volumetric flask with HPLC water. Approximately 5.0 g of Yogurt, Greek-yogurt, and frozen dessert samples were massed accurately and combined with 25ml of ES to be stirred with a magnetic stirrer (~250rpm) for one hour. The solutions were transferred into separate 50 mL centrifuge tubes and centrifuged at 11,000 rpm (15,557 x g) for 25 minutes (Eppendorf model #5804). The supernatant fluid was filtered through a

Whatman No. 4 filter paper (Fisher Scientific) into a beaker. One ml of the filtrate was filtered through a 0.22 μm PVDF filter into a 2 mL HPLC autosampler vial and immediately analyzed with its HPLC method from section 4.2.2.1 (Yüksel and others 2017).

4.2.2.4 Sample Preparation and Extraction Method of Carbohydrates

The ES for carbohydrates contained 135 μL of sulfuric acid and 2.33 grams of fructose made to volume in a 500 mL volumetric flask with HPLC water. Approximately 1.0 g of Yogurt, Greek-yogurt, and frozen dessert samples were massed accurately and combined with 15ml of ES. The solution was transferred into separate 50 mL centrifuge tubes be vortexed for 1 minute at a speed of 9 (Fisher Scientific Vortex Mixer). The centrifuge tubes were than centrifuged at 11,000 rpm (15,557 x g) for 10 minutes (Eppendorf model #5804). The supernatant fluid was filtered through a Whatman No. 4 filter paper (Fisher Scientific) into a beaker. One ml of the filtrate was filtered through a 0.22 μm PVDF filter into a 2 mL HPLC autosampler vial and immediately analyzed with its HPLC method from section 4.2.2.1 (Costa and others 2016).

4.2.2.5 Precision Study

A precision study was conducted using the extraction method outlined in the previous two sections by extracting multiple subsamples of frozen yogurt (10% nonfat yogurt: 90% ice cream) across three days. This type of analysis is conducted to determine the repeatability of a method. It is typically measured by the relative standard deviation (RSD) of the analytes within a day or by comparing analysis of the same sample on different days (Araujo 2009; Green 1996). For this study, the RSD values of each analyte

among five – six subsamples of frozen yogurt were calculated. The RSD values across all three days were also averaged.

4.2.2.6 Recovery Study

A recovery study was conducted among various dairy samples by spiking them with known concentrations of standard compounds. These "spiked" samples were then extracted using the extraction method outlined (Section 4.2.2.3 and 4.2.2.4) and quantified in order to compare the expected concentration with the actual concentration. These samples include yogurt, Greek-yogurt, a control ice cream with no yogurt, a frozen yogurt composed of nonfat yogurt (10% nonfat yogurt: 90% ice cream), and a frozen yogurt composed of Greek-yogurt (10% Greek-yogurt: 90% ice cream). To conduct the study, one amount approximately equivalent to 50-100% of the sample concentration of each respective analyte was added to a solution of sample and ES before stirring or vortexing. Each spike was applied individually to avoid recovery error. The extraction methods for each analyte were then conducted and the resulting supernatant was transferred into a 2 mL HPLC autosampler vial and immediately analyzed with its respective HPLC Method (section 4.2.2.1).

4.2.2.7 Organic Acid and Carbohydrate Analysis of Treatments

The extraction of Organic Acid and Carbohydrate from frozen desserts containing various concentrations of yogurt types and concentrations was performed via isocratic separation in an HPLC instrument. The ES for organic acids was prepared on the day of analysis by combining 135 μL of sulfuric acid and one gram of succinic acid made to volume in a 500 mL volumetric flask with HPLC water. Approximately 5.0 g of a frozen dessert treatment was massed accurately and combined with 25ml of ES to be stirred with

a magnetic stirrer (~250rpm) for one hour. The solutions were transferred into separate 50 mL centrifuge tubes and centrifuged at 11,000 rpm (15,557 x g) for 25 minutes (Eppendorf model #5804). The supernatant fluid was filtered through a Whatman No. 4 filter paper (Fisher Scientific) into a beaker. One ml of the filtrate was filtered through a 0.22 μm PVDF filter into a 2 mL HPLC autosampler vial and immediately analyzed with in an HPLC instrument. The organic acid analysis involved a 0.700 mL/min flowrate that was maintained at a column temperature of 60 °C containing it's a mobile phase of sulfuric acid, acetonitrile, and HPLC water. All organic acids were quantified at 220nm for a run time of 22 minutes.

The ES for carbohydrates contained 135 μL of sulfuric acid and 2.33 grams of fructose made to volume in a 500 mL volumetric flask with HPLC water. Approximately 1.0 g of a frozen dessert treatment was massed accurately and combined with 15ml of ES. The solution was transferred into separate 50 mL centrifuge tubes be vortexed for 1 minute at a speed of 9 (Fisher Scientific Vortex Mixer). The centrifuge tubes were then centrifuged at 11,000 rpm (15,557 x g) for 10 minutes (Eppendorf model #5804). The supernatant fluid was filtered through a Whatman No. 4 filter paper (Fisher Scientific) into a beaker. One ml of the filtrate was filtered through a 0.22 μm PVDF filter into a 2 mL HPLC autosampler vial and immediately analyzed with in an HPLC instrument. The carbohydrate analysis involved a 0.700 mL/min flowrate was maintained at a column temperature of 85 °C containing its respective mobile phase of HPLC water. Carbohydrate analyses were conducted for 15 minutes for each run. All frozen desserts were analyzed in triplicate.

4.3 Experimental design & data analysis

A complete randomized design was utilized to assess differences amongst frozen dessert treatments. Orthogonal contrasts were created to determine the significance of yogurt type, yogurt concentration, and the interaction between these factors. The R statistical software program was used to analyze significant differences ($p < 0.05$) between treatments by one-way ANOVA. The comparisons between the mean values were evaluated by the Tukey HSD test. More detailed ANOVA tables can be located in Appendix B.

Table 4-2 Frozen dessert formulations per 100g basis for products containing various yogurt types

Ingredients / Sample	Ice Cream Mix[a]	Set Yogurt[b]	Greek Yogurt[c]
Control (No yogurt added)	100	0	0
FYA (90%Ice cream mix; 10% set yogurt)	90	10	0
FYB (85%Ice cream mix; 15% set yogurt)	85	15	0
FYC (80%Ice cream mix; 20% set yogurt)	80	20	0
GFYA (90%Ice cream mix; 10% Greek yogurt)	90	0	10
GFYB (85%Ice cream mix; 15% Greek yogurt)	85	0	15
GFYC (80%Ice cream mix; 20% Greek yogurt)	80	0	20

[a] Fat-free ice cream mix (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

[b] Developed with fat-free milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

[c] Developed with fat-free milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

4.4 Results & Discussions

4.4.1 Standard curve results

The internal standard curve information for each compound, including pure compound concentrations, internal standard concentrations, and the area counts for both compounds can be reviewed in Appendix C. The equations and coefficients of determination of each analyte were calculated (Tables 4-3). All coefficients of determination (R^2) that were greater than 0.99 were considered acceptable for quantification purposes.

Table 4-3 Standard curve equations and R^2 values for each analyte

Analytes	Standard Curve Equation	Coefficient of Determination (R^2)
Citric Acid	y = 1.8436x + 0.312	0.9969
Pyruvic Acid	y = 22.366x + 0.0551	0.9969
lactic Acid	y = 0.4313x + 0.1225	0.9912
Uric Acid	y = 56.235x + 0.0116	0.9979
Formic Acid	y = 1.4923x + 0.036	0.9977
Acetic Acid	y = 1.0705x - 0.0057	0.9941
Propionic Acid	y = 0.9259x - 0.0026	0.9994
Butyric Acid	y = 1.0355x - 0.0026	0.9990
Sucrose	y = 4.7445x - 3.0389	0.9946
Lactose	y = 3.3171x - 0.5303	0.9901
Glucose	y = 4.2046x - 0.2639	0.9909
Galactose	y = 0.9664x - 0.0005	0.9923

4.4.2 Precision study results

The precision study took place across three days using a frozen yogurt containing 10% set yogurt and 90% ice cream mix. The %RSD values for three separate days were averaged were calculated (Table 4-4 & 4-5). A variety of sub samples were analyzed

across multiple days to assess the precision of each HPLC methodology. In all cases, all RSD values were well below 5%. No RSD values are available for acetic acid, pyruvic acid, glucose, and galactose as these analytes did not appear in the frozen yogurt sample tested. The precision for extraction of all compounds was deemed acceptable under the circumstances.

Table 4-4 Precision study relative standard deviations (%RSD) for each organic acid

Organic Acid	Day 1 (6 samples)	Day 2 (5 Samples)	Day 3 (5 Samples)	Weighted Average
Citric Acid	1.02%	2.89%	2.06%	1.99%
Pyruvic Acid	-	-	-	-
Lactic Acid	4.19%	3.90%	4.03%	4.04%
Uric Acid	1.88%	1.58%	4.69%	2.71%
Formic Acid	0.94%	2.95%	4.12%	2.67%
Acetic Acid	-	-	-	-
Propionic Acid	3.63%	2.96%	4.91%	3.83%
Butyric Acid	1.47%	4.66%	4.35%	3.49%

Table 4-5 Precision study relative standard deviations (RSD) for each carbohydrate

Carbohydrate	Day 1 (6 samples)	Day 2 (5 Samples)	Day 3 (5 Samples)	Weighted Average
Sucrose	1.30%	3.06%	1.19%	1.85%
Lactose	1.26%	3.33%	2.08%	2.23%
Glucose	-	-	-	-
Galactose	-	-	-	-

4.4.3 Recovery study results

Recovery of all analytes of interest from yogurt, Greek-yogurt, ice cream with no yogurt, frozen yogurt composed of nonfat yogurt (10% nonfat yogurt: 90% ice cream), and a frozen yogurt composed of Greek-yogurt (10% Greek-yogurt: 90% ice cream) with spikes at 50% and 100% of expected concentrations were conducted (Table 4-6 and 4-7). An exception was made for pyruvic acid as this analyte did not appear across any of the dairy products tested. All values for all compounds and spike levels, the global averages across all spike levels across all various compound classes and products, and the average recovery levels across all spike levels for individual compounds fell within a range of 90% and 110% - a range that is deemed to be acceptable.

Table 4-6 Mean recovery % of spiked organic acids in various dairy samples*

Spike + Product / Analyte	50% yogurt	100% yogurt	50% Greek yogurt	100% Greek yogurt	50% Ice cream (no yogurt)	100% Ice cream (no yogurt)	50% frozen yogurt (10% yogurt/ 90% ice cream)	100% frozen yogurt (10% yogurt/ 90% ice cream)	50% frozen yogurt (10% Greek yogurt/ 90% ice cream)	100% frozen yogurt (10% Greek yogurt/ 90% ice cream	Average Per Compound Across All Levels and Samples
Citric Acid	102.01	97.50	94.38	98.69	100.69	102.22	103.50	97.83	109.60	101.25	**100.77**
Lactic Acid	101.14	95.60	103.89	101.55	101.60	101.28	97.23	93.25	97.10	92.03	**98.47**
Uric Acid	96.66	93.29	107.08	96.27	103.97	96.50	102.11	99.54	108.14	96.21	**99.97**
Formic Acid	101.06	93.06	100.13	100.15	96.86	94.15	94.83	102.04	93.04	97.29	**97.26**
Acetic Acid	102.57	102.91	106.43	103.39	95.38	93.11	104.06	100.11	104.58	95.78	**100.83**
Propionic Acid	103.69	107.91	99.44	96.13	107.71	94.27	105.14	103.89	101.00	97.44	**101.66**
Butyric Acid	105.16	93.84	93.59	97.41	97.50	99.49	93.42	104.91	107.02	95.89	**98.82**
Average Across All Compounds by Level	**101.75**	**97.73**	**100.71**	**99.08**	**100.53**	**97.29**	**100.04**	**100.22**	**102.93**	**96.55**	**99.68**

* Units are in average recovery %

Table 4-7 Mean recovery % of spiked carbohydrates in various dairy samples*

Analyte \ Spike + Product	50% yogurt	100% yogurt	50% Greek yogurt	100% Greek yogurt	50% Ice cream (no yogurt)	100% Ice cream (no yogurt)	50% frozen yogurt (10% yogurt/ 90% ice cream)	100% frozen yogurt (10% yogurt/ 90% ice cream)	50% frozen yogurt (10% Greek yogurt/ 90% ice cream)	100% frozen yogurt (10% Greek yogurt/ 90% ice cream	**Average Per Compound Across All Levels and Samples**
Sucrose	102.15	96.69	97.98	91.67	94.28	94.10	97.36	90.63	91.83	95.92	**95.26**
Lactose	92.88	96.58	92.72	94.45	91.18	94.01	95.38	91.45	90.56	102.89	**94.21**
Glucose	95.06	104.43	102.02	98.70	96.18	93.34	99.51	98.66	100.98	99.54	**98.84**
Galactose	104.60	98.48	103.81	98.43	98.58	95.04	100.55	102.30	104.42	101.09	**100.73**
Average Across All Compounds by Level	**98.67**	**99.05**	**99.13**	**95.81**	**95.05**	**94.12**	**98.20**	**95.76**	**96.95**	**99.86**	**97.26**

* Units are in average recovery %

4.4.4 Quantitative organic acid treatment results

Organic acid data collected with HPLC analysis for all frozen dessert treatments was set up using a completely randomized design, one-way ANOVA, and Tukey's HSD with orthogonal contrasts to determine significant differences (Table 4-8). More information regarding in the statistical analysis of each organic acid can be found in Appendix B. The organic acid content of the original yogurt sources was also provided (Table 4-8). The frozen desserts in this study demonstrated significant differences across the models of all organic acids ($P<0.001$). Most models demonstrate that yogurt concentration and type were shown to have highly significant linear ($P<0.001$) and/or quadratic ($P<0.001$) interaction effects on the organic acid concentrations among the treatments. However, there are differences in the impact of these interactions across the treatments.

Citric and formic acid demonstrated a decrease in their average analyte concentration among the treatments as different yogurts and higher concentrations of those yogurt were applied into them. Citric acid demonstrated significant linear and quadratic interaction effects. Compared to other analytes, uric acid only demonstrated a significant quadratic interaction effect while formic demonstrated significant differences through main affects. Lactic, acetic, propionic, and butyric acids all demonstrated an increase in their average analyte concentration among the treatments as different yogurts and higher concentrations of those yogurt were applied into them. This set of analytes demonstrated significant linear and quadratic interaction effects in their respective models. Among the treatments, those containing Greek-yogurt demonstrated a higher impact on the organic acid analytes compared to treatments with set-yogurt.

It is important to note that acetic acid was not present in most treatments except for the treatment with the highest content of Greek-yogurt (GFYC), indicating that this analyte may be either too low to detect or is unequally distributed during production. Propionic and butyric acid concentrations also increased significantly with the addition of higher concentrations Greek-yogurt. GFYB and GFYC have the highest concentrations of these analytes compared to other treatments. Although there are significant differences among treatments regarding pyruvic acid and uric acid ($P<0.001$), the average concentrations amongst the treatments did not change as sharply compared to other analytes. There is also no discernable trend based on the differences between treatments among these analytes. The organic acid profile found within the samples here is similar to work from Adhikari and others (2002). The increase in acetic acid, lactic acid, and propionic acid is similar to work from Yüksel and others (2017) while they assessed the effects of applying green tea powder into frozen desserts.

Table 4-8 Mean concentrations of organic acids of seven frozen desserts with various concentrations of yogurt and Greek yogurt

Sample	Citric Acid*	Pyruvic Acid*	Lactic Acid*	Uric Acid*	Formic Acid*	Acetic Acid*	Propionic Acid*	Butyric Acid*
CTRL	4.0908^{ab}	0.2913^{a}	2.6213^{e}	0.0619^{ab}	0.5079^{a}	0.0000^{b}	0.1355^{d}	0.1068^{d}
FYA	3.3495^{bc}	0.2481^{b}	4.4127^{cd}	0.0588^{cd}	0.2528^{b}	0.0000^{b}	0.5699^{c}	0.3915^{c}
FYB	4.0891^{ab}	0.2539^{b}	4.0494^{cd}	0.0573^{d}	0.5259^{a}	0.0000^{b}	0.0844^{d}	0.3899^{c}
FYC	3.9822^{ab}	0.2899^{a}	5.7152^{b}	0.0605^{bc}	0.4804^{a}	0.0000^{b}	0.1946^{d}	0.1945^{c}
GFYA	4.3457^{a}	0.2981^{a}	3.4899^{de}	0.0621^{ab}	0.4703^{a}	0.0000^{b}	0.2520^{cd}	0.1886^{d}
GFYB	4.1331^{ab}	0.2938^{a}	5.0584^{bc}	0.0639^{a}	0.4406^{a}	0.0000^{b}	3.8761^{b}	3.3859^{b}
GFYC	2.7095^{c}	0.2485^{b}	9.2759^{a}	0.0615^{ab}	0.2765^{b}	0.0950^{a}	4.6879^{a}	3.8980^{a}
Yogurt	3.0225	0.1893	25.6611	0.0527	0.2476	0.0969	0.2546	1.6364
Greek Yogurt	3.4609	0.1909	27.9149	0.0723	0.2668	0.0989	4.4569	5.1293

There are no significant differences at $p<0.05$ among the samples with the same superscript letter.
*Units are in (µg/5g of sample)

4.4.5 Quantitative carbohydrate treatment results

Carbohydrate data collected with HPLC analysis for all frozen dessert treatments was set up using a completely randomized design, one-way ANOVA, and Tukey's HSD with orthogonal contrasts to determine significant differences (Table 4-9). More information regarding the statistical analysis of each organic acid can be found in Appendix B. The carbohydrate content of the original yogurt sources was also provided (Table 4-9). The frozen desserts in this study demonstrated significant differences across the models of all carbohydrates. All models showed significant differences among the analytes ($P<0.01$). These models demonstrate that yogurt concentration and type were shown to have highly significant quadratic interaction effects ($P<0.001$) on the carbohydrate concentrations among the treatments. However, there are differences in the impact of these interactions across the treatments.

Sucrose and lactose demonstrated a decrease in their average analyte concentration among the treatments as different yogurts and higher concentrations of those yogurt were applied into them. Glucose and galactose showed similar results to that of citric and formic acids; A decrease in their average analyte concentration among the treatments was observed as different yogurts and higher concentrations of those yogurt were applied into them. Although there are significant differences among treatments in regard to glucose ($P<0.001$), the average concentrations amongst the treatments did not change as sharply compared to other analytes. The decrease in lactose is similar to work from Costa and others (2016) as they assessed the organic acid profile of yogurts after the application of various microorganisms.

Table 4-9 Mean concentrations of carbohydrates of seven frozen desserts with various concentrations of yogurt and Greek yogurt

Sample	Sucrose*	Lactose*	Glucose*	Galactose*
CTRL	59.8765[a]	46.0554[a]	13.9830[abc]	11.1315[a]
FYA	58.7728[ab]	45.5731[a]	14.6123[a]	11.3332[a]
FYB	58.0404[bc]	43.5349[b]	13.3741[bc]	11.4658[a]
FYC	56.1261 [d]	38.9045[c]	12.0063[d]	9.5385[b]
GFYA	58.0088[bc]	42.4687[b]	13.5712[bc]	10.8086[ab]
GFYB	57.3099[c]	40.4606[c]	13.2104[c]	10.4277[ab]
GFYC	57.0884[cd]	40.2241[c]	14.1835[ab]	9.5385[a]
Yogurt	N/A	22.6828	5.7689	7.2931
Greek Yogurt	N/A	21.5821	6.2102	7.7682

There are no significant differences at $p<0.05$ among the samples with the same superscript letter.
*Units are in (mg/g of sample)

4.5 Conclusions

The chemical compounds used to develop various standard curves functioned well for method validation and overall analysis of organic acid and carbohydrate in frozen dessert treatments containing various concentrations and types of yogurts. The precision study suggests that extraction of all compounds was repeatable, with all compounds falling below 5% RSD, an acceptable level for analysis. The recovery study demonstrated the efficiency of this method regardless of the various food matrices that were utilized. Based on the results of these studies, the extraction of organic acids and carbohydrates and their subsequent analysis was conducted with efficiency and sufficient separation. Citric acid, formic acid, sucrose, lactose, and glucose demonstrated a decrease in their average concentration as more of any yogurt type was applied to the control ice cream; on the other hand, the concentration of lactic acid, acetic acid, propionic acid, and butyric acid increased in concentration as more of any yogurt type was applied to the control ice cream.

CHAPTER 5

Descriptive Sensory Analysis of Low-Fat Frozen Desserts Containing Strained Yogurt

5.1 Introduction

Due to an increased health-consciousness from U.S. consumers, more food companies have begun producing health-oriented food products. In addition to basic nutrition, consumers are now expecting that their food should provide increased benefits with as few additives as possible (Hertanto and Pramono 2019). Among the many products available, frozen low-calorie ice creams such as frozen yogurts are becoming popular in the United States and can serve as an ideal delivery system for additional functional ingredients (Peres and others 2018). However, most functional foods are single ingredient based and do not deliver multiple functional ingredients at once. Greek yogurt has been shown to provide a combination of health benefits to consumers and has recently become a popular product that is accessible and affordable (Drewnowski 2018). The goal of this study was to formulate a frozen dessert with Greek yogurt and to compare its descriptive attributes to frozen desserts composed of ice cream and regular frozen yogurt.

A high-quality ice cream has to have proper characteristics in body, melt-down and flavor; the amounts of fat, nonfat milk solids, sugar, stabilizer, and flavoring used in the mixes are critical factors in the development of frozen dessert products (Salam and others 1981). It is important that additional or replacement ingredients should be effective in their purpose while minimizing any possible defects. For example, Soukoulis and Tzia

(2010) discovered that using alternative sweeteners in ice creams is possible, but may cause adverse effects on ice crystallization phenomena, glass transition temperature and rheological properties. According to Lin (2012), applying multiple functional ingredients into an ice cream product (e.g. dietary fiber, probiotics, prebiotics, and antioxidants) significantly increased the panelists perception of gooeyness, gumminess, creaminess, mouth coating, sweetness, sweetness aftertaste, and wood flavor aftertaste, but decreased the perception of hardness and iciness amongst all products. Reducing the fat content of ice cream products contributes to the decrease in caloric intake, but the viscosity of the products will be significantly affected the more fat is removed from the product (Mostafavi 2019). In contrast, panelists assessing low-fat frozen yogurts with fat replacers, such as Frutafit TEX! and inulin, perceived a decrease in iciness (Frank 2014). Panelists are able to perceive differences in product attributes despite different descriptive methodologies. According to Ahadzi (2019), panelists that analyzed frozen dairy-based products with the Quantitative Descriptive Analysis (QDA®) method observed low perceptions of taste and flavor attributes, but demonstrated similar results with Temporal Dominance of Sensation (TDS) and Temporal Check All That Apply (TCATA) methodologies.

There are a variety of types of yogurts, such as set, stirred, sweet drinking, fruit-based, yogurt-cheese, and frozen yogurts, that provide their own unique flavors and textures (Yildiz 2010). Compared to its counterparts, Greek yogurt contains higher concentrations of important nutrients (e.g., calcium, potassium, phosphorus), increased protein content, lower pH, and a higher casein/ whey ratio (Bridge and others 2019; Rizzoli and Biver 2018). According to Esmerino and others (2017), attributes such as

milk flavor, bitter, astringent, sour, and gritty are used to describe Greek yogurt. Work from Atamian and others (2014) has shown that Greek yogurt products made from milk with various fat concentrations can significantly differ in the sensory attributes of syneresis, compactness, goaty, flavor, shininess, bitter flavor, denseness, and melting rate. In another study, Greek yogurt products with added sucralose, araticum (Annona crassiflora) and mangaba (Hancornia speciosa) did not experience negative characteristics in their respective sensory profiles (Amaral and others 2020).

Descriptive analysis is a method which involves the training of panelists to quantify specific sensory attributes for appearance, flavor, texture and aftertaste (O'Sullivan 2011). The objective of the present study was to compare the formulation and sensory characteristics of frozen dessert products containing Greek yogurt to common frozen desserts using descriptive analytical methods.

5.2 Materials & methods

5.2.1 Materials

Fat-free ice cream mix (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL) was used in the study. Set yogurt and Greek yogurt was manufactured with Prairie Farms fat free skim milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL) and Yogourmet freeze-dried yogurt starter (Yogourmet, Canada). This starter culture contains skim milk powder, sucrose, and active bacterial cultures (*L. bulgaricus, S. thermophilus, L. acidophilus*).

5.2.2 Methods

5.2.2.1 Preparation of yogurt

To produce the set yogurt, skim milk was heated to 80 ºC for 25 seconds, and then cooled to 40 ºC and inoculated with the starter culture (Yogourmet, Canada) which contains 1 billion CFU/gram (Frank 2014). This solution was allowed to ferment to a pH of 4.6 (approx. 4 hours). The yogurt was chilled overnight to set the yogurt.

5.2.2.2 Preparation of Strained (Greek) Yogurt

Greek Style yogurt was prepared according to the methods by Aloglu and Seckin (Şanlıdere Aloğlu and Öner 2013; Seckin and Ozkilinc 2011). The straining time of strained yogurt was reduced to approximately 5.5 hours to improve production.

5.2.2.3 Frozen Dessert Manufacture

Frozen yogurt treatments were prepared according to the method by Li and others (1997). According to Marshall and others (2003), at least 5% of the weight of the total mix should be yogurt. We used six frozen dessert treatments: three frozen yogurts containing 10, 15, and 20% added set yogurt, and three frozen yogurts containing 10, 15, and 20% added Greek Style yogurt. Frozen yogurt mixes were prepared in 2.5-gallon batches. Yogurts were manually stirred with their respective ice cream mixes prior to freezing using a stainless-steel spiral mixer (Warner, China) in order to breakdown the gels formed during incubation for three minutes. Table 3-1 describes the specific formulation of each product. The stirred frozen yogurt mixes with a semi-liquid consistency were frozen in an ice cream freezing machine (Taylor 0702, Taylor Co. Rockton, IL) in 2.5-gallon batches for approximately 10-20 minutes depending on the treatment. The frozen yogurt batches were packed into and tightly sealed in two-ounce

portion cups (Eco-Products, Boulder, CO). Containers were labeled and then placed in a freezer at -40 °C for hardening and storage.

5.2.2.4 Sensory Evaluation of Frozen Desserts

5.2.2.4.1 Descriptive Panel and Training of Panelists

The seven frozen dessert samples were evaluated by eleven trained panelists. The panelists, who consisted of graduate and undergraduate students at the University of Columbia – Missouri, were recruited and chosen based on their availability and willingness to participate in the project; all panelists were provided a consent form for their participation (Appendix D). The eleven panelists were ballot trained for six 1-hour training sessions over the course of one month. In this study, the sensory attributes were decided upon by contributions from both the panel leader and panelists. The references were decided upon the by panel leader, according to previous studies, instead of by the panelists. During the training period, the entire descriptive panel received instructions regarding the attributes, the references, and the test procedures from the panel leader. Test samples containing various low and high intensities of the decided attributes were formulated for training by the panel leader. Panelists were instructed to understand that the perceived intensities of each reference provided were to be considered as being equal to 12 (i.e. 12 cm), and were asked to make a vertical line at the perceived intensities of the attributes for sampled frozen desserts across the 15-cm unstructured line scales anchored at the two ends with low intensity = 0 and high intensity = 15 using a paper ballot (Appendix D). To reduce carry-over effect, panelists were instructed to cleanse their palates by chewing a small piece of unsalted crackers and by rinsing with water between samples.

The attributes and references for the frozen desserts were slightly modified based on panelist feedback after panelists had participated in the first training session. A total of twenty-two attributes consisting of characteristics describing the appearance, scoopability, texture, flavor and aftertaste of the desserts were used in the test. These attributes are listed in Table 5-2 together with their definitions and reference materials, where they were supplied.

Before the actual testing, an informal pretest was performed using the official paper ballot (Appendix D) to evaluate if all panelists had thoroughly understood these attributes and were able to communicate their perceptions correctly. The other purpose of this pretest was for panelists to gain experience with the ballot test before performing the actual testing. During the pretest, the descriptive panel evaluated three randomly generated test samples containing various combinations of attributes in duplicate. Afterwards, the informal data was immediately statistically analyzed to evaluate panelists' consistency. Since all panelists were consistent in evaluating the pretest samples, no extra individual training sessions were required.

5.2.2.4.2 Descriptive Test

Samples were evaluated in individual booths under normal light using paper ballots. Panelists evaluated seven samples per session, the first being a warm-up sample. The order of presenting the seven samples was determined by the R statistical program. Each frozen dessert was made and evaluated in three replications; Panelists evaluated each replication in two sub-replications. All tests for the three replications were finished within a two-week time period. Three-digit random codes were generated for each

sample to perform randomized product presentation arrangements across each session and to avoid positional biases. Prior to analysis, frozen dessert samples were tempered and stored at least 24 hours at -19°C to -15°C before being served at -15°C to -11°C. Panelists were asked to cleanse their palates by chewing a small piece of an unsalted cracker and by rinsing with water at the beginning of the test and between samples to minimize carry-over and fatigue effects. The perceived intensity of each attribute for each product was evaluated on each ballot using a ruler.

5.3 Experimental design and data analysis

A 14 X 14 Williams modified Latin-square design was used to determine the serving order for all panelists (Næs 1996). As the 14 x 14 Williams design has only 14 slots for each panelist, the full design was repeated 3 times. Each design was utilized as one replication and was split in half column-wise to create the sub-replication. This created positional and pairwise balance within the design for the first-order carryover effect. Certain distribution orders were randomly removed from the design to accommodate the population of 12 panelists in the study. The distribution order of treatments to each panelist can be found in Appendix E.

In this study, because each single replicate was finished before the next one was started, the replicate effect has a time interpretation. A mixed model of analysis of variance (ANOVA) was applied for the analysis of sensory data to determine significant differences among the products at $p < 0.05$ (Appendix F). The main effect of product was designed as a fixed effect, whereas assessor (= panelist), replicate, assessor-product interaction, assessor-replicate interaction, product-replicate interaction and assessor-

product-replicate interaction were considered random affects (Liou 2006). A correlation matrix was created to explore relationships among the ratings of each product. Multivariate analysis of variance (MANOVA) using the Wilk's lambda statistic was used to determine if there was an overall significant difference among products when comparison was based on using all the dependent variables.

A principal component analysis (PCA) was performed on the covariance matrix of the mean values of the 7 frozen desserts (n=7) for all sensory attributes. Pearson's correlation for the original attributes (n=7) was also calculated to aid interpretation of the individual PCs in terms of the original attributes. Dissimilarity matrix using Euclidean distance for a rectangular array by comparing the rows or the columns was established to determine the similarity among products. Descriptive data was analyzed using the R statistical software and the PCA and dissimilarity matrix was conducted using XLSTAT-2020 (XLSTAT, Addinsoft, USA).

Table 5-1 Frozen dessert formulations per 100g basis for products containing various yogurt types

Ingredients / Sample	Ice Cream Mix[a]	Set Yogurt[b]	Greek Yogurt[c]
Control (No yogurt added)	100	0	0
FYA (90%Ice cream mix; 10% set yogurt)	90	10	0
FYB (85%Ice cream mix; 15% set yogurt)	85	15	0
FYC (80%Ice cream mix; 20% set yogurt)	80	20	0
GFYA (90%Ice cream mix; 10% Greek yogurt)	90	0	10
GFYB (85%Ice cream mix; 15% Greek yogurt)	85	0	15
GFYC (80%Ice cream mix; 20% Greek yogurt)	80	0	20

[a] Fat-free ice cream mix (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

[b] Developed with fat-free milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

[c] Developed with fat-free milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

Table 5-2 Sensory attributes, definitions of sensory attributes and references for the descriptive panelists

Attribute		Definition	Reference *
Appearance	Sheen	The perception of white light reflected off the surface of the product.	Ref 12 = Gumminess Ref Ref 3 = 0% overrun Ref
Scoopability	Gooeyness	The resemblance of caramel/ taffy during scooping.	Ref 12 = Gooeyness ice cream sample [a] Ref 3 = store brand ice cream
	Hardness	The resistance of ice cream to scooping.	Ref 15 = Ice cream stored at -40°C (cannot be scooped) Ref 3 = store brand ice cream
Texture	Melting Rate	The seconds to completely melt a spoonful of ice cream while rubbing it gently against the roof of the mouth with the tongue.	
	Creaminess	Degree of fat-like, full-body liquids after melting in mouth.	Ref 12 = 60% cream + 40% whole milk Ref 3 = 10% cream + 90% whole milk
	Denseness	Compactness of cross section of the sample after biting completely through.	Ref 12 = refrozen store brand ice cream Ref 3 = store brand ice cream
	Iciness	Perception of crystal-like particles in the sample. The measurement needs to be taken right after sample has been placed in the mouth.	Ref 12 = iciness ice cream sample Ref 3 = store brand ice cream
	Smooth	The force necessary to compress sample against the roof of the mouth.	Ref 12 = Pudding Ref 3 = store brand ice cream
	Gumminess	The perception of stickiness (like gum) between tongue and roof of mouth when rubbing sample against the roof of the mouth.	Ref 12 = Gumminess ice cream sample [b] Ref 3 = store brand ice cream
	Mouth coating	Degree of fatty mouth or coated mouth after tasting.	Ref 12 = pudding Ref 3 = store brand ice cream

* Ref 3, 12 and 15 are the references represent the intensity of 3, 12 and 15 on a 15 cm unstructured scale line anchored with low intensity=0 and high intensity= 15.

[a] Gooeyness and gumminess ice cream were made by adding 20 grams of fiber into 80 grams of control ice cream mix.

[b] Iciness ice cream was made by control ice cream mix and whole milk at 1:1 (v/v) ratio.

Table 5-2 Sensory attributes, definitions of sensory attributes and references for the descriptive panelists (cont.)

Attribute		Definition	Reference *
Flavor	Sourness flavor	The intensity of sourness as reference	Ref 12 = 10% acid whey in whole milk
	Fatty flavor	The intensity of fat as reference	Ref 12 = Whole milk Ref 3 = Skim milk
	Bitterness flavor	The intensity of bitterness as reference	Ref 12 = 0.1% caffeine in whole milk
	Alkaline flavor	The intensity of alkaline Flavor as reference	Ref 12 = Alkaline water
	Sweet flavor	The intensity of sweetness (sucrose) as reference	Ref 12 = 15% (w/v) sugar solution
	Milky flavor	The intensity of whole milk as reference	Ref 12 = whole milk Ref 3 = 50% whole milk + 50% water
Aftertaste	Sourness aftertaste	The intensity of sourness flavor after swallowing	The same reference with sourness
	Fat aftertaste	The intensity of fat flavor after swallowing	The same reference with fat
	Bitterness aftertaste	The intensity of bitterness flavor after swallowing	The same reference with bitterness
	Alkaline aftertaste	The intensity of alkaline flavor after swallowing	The same reference with alkaline
	Sweet aftertaste	The intensity of sweetness flavor after swallowing	The same reference with sweetness
	Milky aftertaste	The intensity of milky flavor after swallowing	The same reference with milky

* Ref 3, 12 and 15 are the references represent the intensity of 3, 12 and 15 on a 15 cm unstructured scale line anchored with low intensity=0 and high intensity= 15.

5.4 Results & discussions

5.4.1 Analysis of variance (ANOVA)

A mixed model ANOVA method was used to understand the differences among the attributes for the various products. Results in Table 5-3 show that there were many significant differences for almost two-thirds of the attributes. In general, panelists could distinguish differences among the corresponding attributes of the seven frozen desserts with various yogurt types and yogurt concentrations. Textural attributes that could not be distinguished, such as *rate of melt* and *denseness,* could be due to the minimal differences in overrun and significant differences in melting rate among treatments (Table 3-2). Among the products, the control ice cream showed on average less intensity for the attributes such as *hardness*, *sour flavor* and *sour aftertaste*, whereas it had higher intensity ratings for *gooeyness*, *creaminess*, *smoothness*, *gumminess*, *mouth coating*, *fat flavor*, *sweet flavor*, *milk flavor*, *fat aftertaste*, *sweet aftertaste,* and *milk aftertaste* (Appendix E).

These results are in partial agreement with previous studies. Isik and others (2011) demonstrated similar differences in hardness, iciness, and sweetness differences in their frozen yogurt analysis in their low fat and low sugar frozen dessert formulations. Frank (2014) reported that frozen desserts made with yogurts containing fat replacer scored lower in the iciness category compared to the Greek yogurt that was added to this study. In comparison to Soukoulis and others (2008) that demonstrated the positive and negative effects of hydrocolloids, Greek yogurt was found to increase the *hardness* and

sourness of frozen desserts products in this study – essentially providing a higher average score in these attributes in comparison to treatments with set yogurt.

Table 5-3 Summary of the mixed-model ANOVA conducted on seven frozen desserts for each attribute in the descriptive analysis

Effect	Attribute	Num DF	Den DF	F-Value	Pr > F	Significance
Appearance	**Sheen**	6	12	1.1169	0.4081	
Scoopability	**Gooeyness**	6	15.61	7.5369	0.0006323	***
	Hardness	6	60	6.3075	3.492e-05	***
Texture	**Rate of Melt**	6	13.934	1.23	0.3488	
	Creaminess	6	13.646	5.2683	0.005264	**
	Denseness	6	19.532	0.5199	0.7863	
	Iciness	6	13.752	2.6475	0.0635	
	Smoothness	6	14.876	4.5262	0.008342	**
	Gumminess	6	60	4.4008	0.0009496	***
	Mouth Coating	6	60	4.2025	0.001359	**
Flavor	**Sour Flavor**	6	25.894	13.032	9.285e-07	***
	Fat Flavor	6	60	7.2305	7.779e-06	***
	Bitterness Flavor	6	13.871	1.4937	0.251	
	Alkaline Flavor	6	60.04	1.0315	0.414	
	Sweet Flavor	6	60	15.755	9.133e-11	***
	Milk Flavor	6	60	7.0517	1.035e-05	***
Aftertaste	**Sour Aftertaste**	6	22.059	9.5256	3.272e-05	***
	Fat Aftertaste	6	60	6.3243	3.396e-05	***
	Bitter Aftertaste	6	60	0.9639	0.4574	
	Alkaline Aftertaste	6	192	0.574	0.7507	
	Sweet Aftertaste	6	22.686	7.5455	0.000156	***
	Milk Aftertaste	6	25.428	6.2557	0.0003899	***
*** ** *** Significant at P<0.05, 0.01, and 0.001, respectively**						

5.4.2 Multivariate analysis of variance (MANOVA)

Twenty-two attributes, including one appearance attribute, two scoopability attributes, seven texture attributes, six flavor attributes and six aftertaste attributes were used to describe the differences in the sensory properties of the seven frozen dessert products with different types and concentrations of yogurt. A multivariate analysis of variance (MANOVA) was performed to evaluate whether significant differences existed among the products (Table 5-4.). Regardless of the statistical test utilized, the p-value for the various attributes in the model is less than 0.05, which showed there were significant differences between attributes for the products.

Table 5-4 Statistics and significance of various effects on all attribute measures for seven frozen dessert samples

Statistic	Value	Num DF	Den DF	F Value	Pr > F
Wilks' test (lambda)	0.381	132	2532	3.464	< 0.0001
Pillai's test (Trace)	0.798	132	2634	3.059	< 0.0001
Hotelling-Lawley's test (Trace)	1.207	132	2594	3.952	< 0.0001
Roy's test (Greatest Root)	0.808	22	439	16.117	< 0.0001

5.4.3 Correlation matrix

A correlation matrix was generated to understand the relationship among the 22 sensory attributes for the frozen desserts with various yogurt types. In this study, *mouth coating*, *smoothness*, *gumminess*, and *gooeyness* were highly correlated with each other as shown in Table 5-5 ($p<0.05$ at Pearson coefficients). These results are similar to those from Liou (2006). In addition, the *creaminess* and *smoothness* texture attributes had positive correlations with *sweet*, *milk*, and *fat* flavors and aftertaste attributes. *Bitter flavor* and *bitter aftertaste* also had positive correlations with *iciness* and *hardness* (Table 5-5).

The flavor attributes were positively correlated with their corresponding aftertaste attributes. In other words, *sour*, *bitter*, *fatty*, *alkaline*, *sweetness*, and *milky* flavors had significant positive correlations with their respective aftertastes. In addition, two groups of positive correlations also existed: 1) *sourness*, *bitterness*, and *alkaline* attributes and 2) *sweet*, *fat*, and *milky* attributes. *Sourness flavor* was positively correlated with *alkaline* and *bitterness aftertaste* attributes. *Sweet flavor* was correlated positively with *fat* and *milky aftertastes*; *fat flavor* was correlated positively with *sweet* and *milky aftertastes* (Table 5-5).

Table 5-5 Pearson Correlation of 22 sensory attributes for frozen desserts with various yogurt types and concentrations (n=7)

	SourFlv	SourAft	AlkFlv	AlkAft	BitFlv	BitAft	Shn	Ici	Hrd	Mor	SwtAft	MlkAft	FatFlv	FatAft	SwtFlv	MlkFlv	Dns	Crm	Smth	Gooy	Gmy	MtCt
SourFlv	1																					
SourAft	**0.69**	1																				
AlkFlv	**0.21**	**0.2**	1																			
AlkAft	**0.12**	**0.11**	**0.73**	1																		
BitFlv	**0.18**	**0.15**	**0.33**	**0.27**	1																	
BitAft	**0.16**	**0.13**	**0.25**	**0.3**	**0.61**	1																
Shn	**0.11**	−0.02	−0.03	−0.07	0.08	**0.16**	1															
Ici	0.07	**0.1**	0.09	0.05	**0.14**	**0.14**	**0.33**	1														
Hrd	**0.24**	0.07	−0.01	0.01	**0.12**	**0.11**	**0.1**	**0.18**	1													
Mor	**0.24**	**−0.1**	−0.09	**−0.16**	−0.04	−0.07	−0.03	−0.06	**0.29**	1												
SwtAft	**−0.14**	0.01	**0.1**	0.07	**−0.14**	**−0.2**	**−0.15**	**−0.15**	**−0.31**	**−0.29**	1											
MlkAft	**0.09**	−0.05	**0.15**	0.09	**−0.1**	**−0.15**	**−0.22**	**−0.16**	**−0.29**	**−0.2**	**0.69**	1										
FatFlv	0.07	−0.09	0.07	**0.09**	−0.09	**−0.1**	−0.02	**−0.16**	**−0.09**	0.01	**0.46**	**0.52**	1									
FatAft	−0.05	0.02	**0.18**	**0.17**	0	−0.06	**−0.15**	−0.06	**−0.19**	**−0.28**	**0.67**	**0.67**	**0.73**	1								
SwtFlv	**0.18**	**−0.25**	0	0.02	−0.23	**−0.22**	**−0.21**	**−0.32**	**−0.22**	0	**0.53**	**0.46**	**0.6**	**0.46**	1							
MlkFlv	-0.07	**−0.2**	**0.1**	0.05	−0.22	**−0.11**	**−0.17**	**−0.23**	**−0.17**	0.06	**0.39**	**0.66**	**0.61**	**0.47**	**0.66**	1						
Dns	**0.13**	0.03	**0.19**	**0.11**	−0.07	−0.07	**−0.12**	**−0.17**	**0.16**	−0.04	**0.29**	**0.29**	**0.29**	**0.32**	**0.26**	**0.31**	1					
Crm	-0.08	**−0.13**	0.08	0.03	**−0.23**	**−0.18**	−0.04	**−0.36**	**−0.25**	−0.05	**0.42**	**0.43**	**0.53**	**0.43**	**0.57**	**0.53**	**0.42**	1				
Smth	0.02	**−0.15**	−0.04	−0.06	**−0.12**	**−0.17**	−0.03	**−0.36**	−0.06	**0.13**	**0.22**	**0.23**	**0.5**	**0.29**	**0.46**	**0.4**	**0.26**	**0.63**	1			
Gooy	**-0.13**	**−0.13**	**−0.2**	**−0.16**	**−0.03**	0.01	**0.23**	**−0.11**	**−0.35**	−0.07	−0.01	−0.04	**0.14**	−0.01	**0.1**	0.05	**−0.2**	**0.2**	**0.28**	1		
Gmy	0.02	−0.09	**−0.15**	**−0.09**	0.11	**0.13**	**0.16**	**−0.16**	0	0.04	**−0.14**	**−0.15**	**0.11**	−0.08	0.04	0.04	0	0.08	**0.2**	**0.28**	1	
MtCt	**0.15**	−0.03	−0.01	0.03	0.01	−0.01	**0.14**	**−0.28**	0.02	0.07	−0.02	**0.1**	**0.39**	**0.21**	**0.28**	**0.27**	**0.1**	**0.35**	**0.35**	**0.09**	**0.42**	1

In bold, significant values (except diagonal) at the level of significance alpha=0.50 (two-tailed test)

SourFlv: Sour Flavor, SourAft: Sour Aftertaste, AlkFlv: Alkaline Flavor, AlkAft: Alkaline Aftertaste, BitFlv: Bitterness Flavor, BitAft: Bitter Aftertaste, Shn: Sheen, Ici: Iciness, Hrd: Hardness, Mor: Rate of Melt, SwtAft: Sweet Aftertaste, MlkAft: Milk Aftertaste, FatFlv: Fat Flavor, FatAft: Fat Aftertaste, SwtFlv: Sweet Flavor, MlkFlv: Milk Flavor, Dns: Denseness, Crm: Creaminess, Smth: Smoothness, Gooy: Gooeyness, Gmy: Gumminess, MtCt: Mouth Coating,

5.4.4 Principal component analysis (PCA)

Principle component of analysis (PCA) was used to describe the interrelationships among multiple dependent variables among the seven frozen dessert products. Since the descriptive data was measured on the same scale and showed limited variance, the correlation model was used to account for judges' different usage of scales; the correlation model standardized the results of each panelist description of each attribute so that the variances of each attribute (variable) would equal to 1 (Borgognone and others 2001). In general, the PCA is based on a two-dimensional graph that shows a visual representation of loaded attributes and products in the PCA technique (Lever and others 2017). Only heavily loaded attributes should be used to describe the nature of each principal component (PC). Although all loadings are meaningful in PCA, small loadings mean that the factor is not related to those variables (Kemp and others 2018). .

The first three PCs accounted for 90.85% of the total variance in the data set. The first principal component (PCI) explained 66.59% of the variance unlike the second (PCII) and third (PCIII) principal components described the remaining 12.81% and 9.44%, respectively. Among the first two principal components (Figure 5-1), PCI was characterized by high ratings and positive values of *sweet flavor, milk flavor, fat flavor, sweet aftertaste, fat milk aftertaste, fat aftertaste, creaminess, gumminess,* and *mouth coating*. PCI also demonstrated high negative ratings for *hardness, bitter aftertaste, sour flavor, sour aftertaste,* and *alkaline aftertaste*, contributing more to the negative side of the first dimension. For PCII, the attributes of *denseness, smoothness, bitter flavor, alkaline flavor, creaminess,* and *sour aftertaste* by high ratings and positive values.

The principal component comparison of PCI and PCIII (Figure 5-2) share similarities to Figure 5-2 in that the attributes driving PCI have not changed. However, unlike PCII, the third principal component, PCIII, was characterized by high ratings and positive values of *sheen, bitter flavor, gumminess*, *iciness*, and *mouth coating*. As a result, attributes such as *sheen* and *iciness* contribute positively to the description of frozen desserts in the PCI and PCIII model (Figure 5-2) compared to the PCI and PCII model (Figure 5-1) as result of the positive loadings of these attributes in the third principal component in the y-axis. It is important to note that despite the principal component, *gooeyness*, *gumminess*, and *mouth coating* were always found to have positive loadings. As PCI contributed most of the variance in both PCA models (approximately 66%), the treatments can be differentiated by the aforementioned positive and negatively loaded attributes on the 1st dimension of each model compared to the attributes positively loaded on PCII (12.81%) and PCIII (9.44%).

Most texture attributes were drivers in the PCI vs PCII plot (Figure 5-1), except for iciness. Iciness was loaded in the negative direction in the first two dimensions compared to other attributes and only contributed positively to the third dimension. Most loadings were positioned in both positive and negative X dimension among the generated plots. Since texture attributes persisted among all principal components, the flavor loadings significantly impacted the structure of each plot. For example, since the *sweet*, *fat*, and *milky flavors* is loaded positively on PCI, their positively correlated texture attributes can also be found in the same direction (e.g., *smoothness* and *creaminess*). As these attributes have positive correlations with each other, they tend to overlap one another in their respective plots. This phenomenon can be seen in both the PCI and PCII

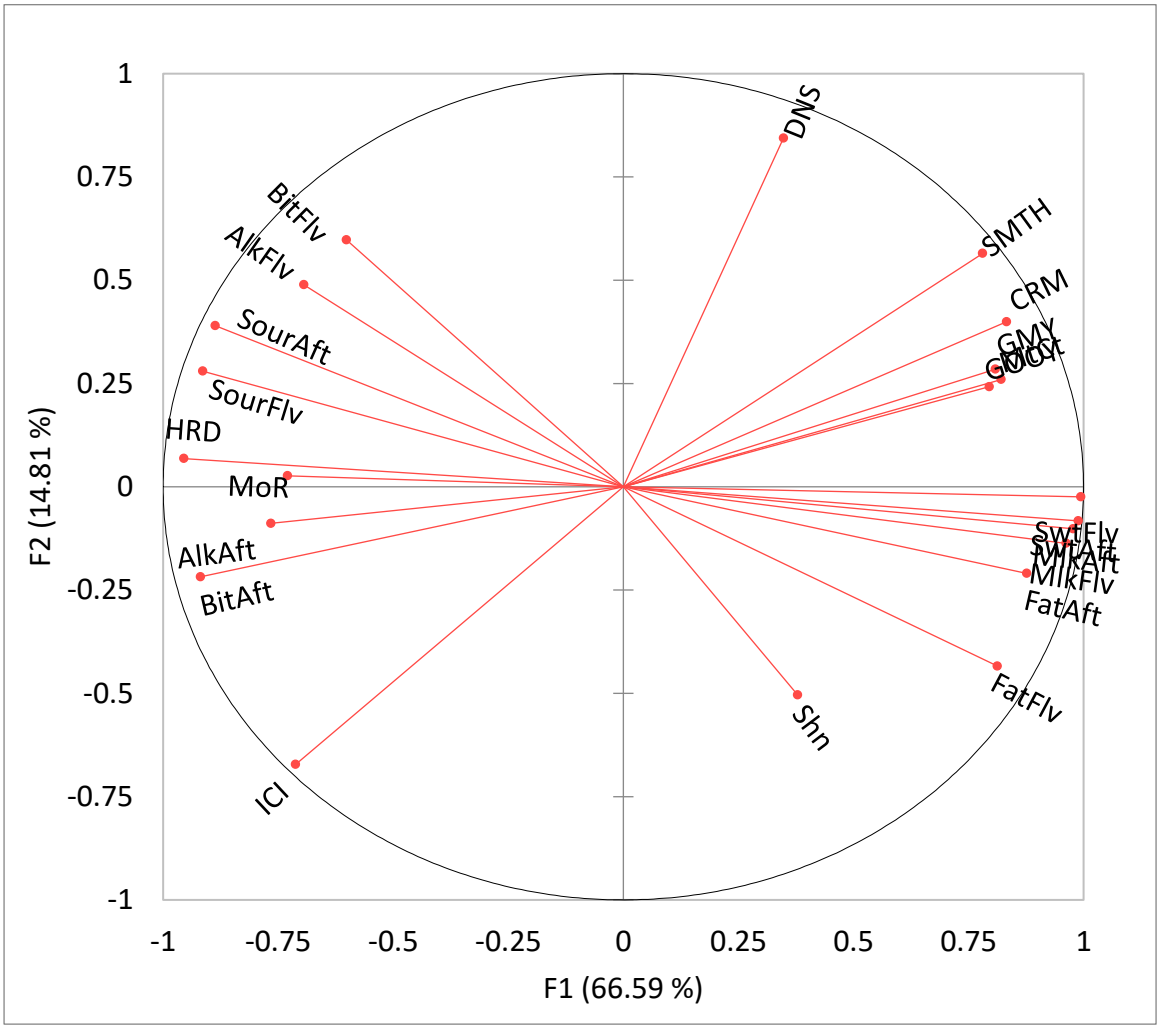
plot (Figure 5-1) and the PCI and PCIII plot (Figure 5-2). In contrast, the *sourness*, *bitterness*, and *alkaline* flavors are loaded on the negative dimension with their respective correlated texture attributes in the same plots.

The control ice cream was always loaded at the top right quadrant of each generated PCA map, regardless of the principal component (Figures 5-3 & 5-4). From the mixed-model ANOVA results, the control ice cream on average showed high intensity in *gooeyness*, *creaminess*, *smoothness*, *gumminess*, *mouth coating*, *fat flavor*, *sweet flavor*, *milk flavor*, *fat aftertaste*, *sweet aftertaste*, and *milk aftertaste* compared to all other products. In other words, the control ice cream was loaded on the right side of all PCA maps due to its correlation with the aforementioned attributes while demonstrating a low intensity in attributes such as *hardness*, *sour flavor*, and *sour aftertaste*.

Treatments, such as FYA, FYB, and GFYA, were loaded on the upper-right side of each generated PCA maps, similar to the control ice cream product. From the mixed-model ANOVA results, these products on average showed a high intensity in attributes similar to the control ice cream and show no significant differences with the control ice cream. However, FYA was significantly higher in *gooeyness*, *creaminess*, *smoothness*, *fat flavor*, and *sweet flavor* compared to FYB and GFYA. As a result, these products were loaded on the upper right side of the PCA map in the PCI and PCII plot (Figure 5-3). In contrast, the same products were loaded on the lower right side of the PCA maps in the PCI and PCIII plot (Figure 5-4). This is a result of the *fat flavor*, *milk flavor*, *smoothness*, and *creaminess* attributes being found on the negative axis of the third principal component of these plots; as PCIII represented the Y-dimension, the products were pushed to the lower right side of their respective maps.

The remaining products, FYC, GFYB, and GFYC, were loaded on the left side of all generated PCA maps. These products on average showed a high intensity in *iciness*, *hardness*, and *sourness* compared to other attributes. However, GFYB was significantly higher in *iciness* compared to all products while GFYC was significantly higher in sourness and *hardness* attributes. As a result, these products were loaded on the left side of the PCA maps in the PC I and PC II plot (Figure 5-3) and PC I and PC III plot (Figure 5-4). The PCA results demonstrated that frozen dessert treatments have great variation in flavor and texture attributes when various concentrations of yogurt and Greek-yogurt are applied to them.

Figure 5-1 Principal component analysis of 22 attributes for seven frozen desserts on PC I and PC II (Correlation-Pearson model)



Parenthesis denotes the percent explained by the corresponding PC dimensions					
Attribute Code:					
Shn	Sheen	**Smth**	Smoothness	**SwtFlv**	Sweet Flavor
Gooy	Gooeyness	**Gmy**	Gumminess	**MlkFlv**	Milk Flavor
Hrd	Hardness	**MtCt**	Mouth Coating	**SourAft**	Sour Aftertaste
Mor	Rate of Melt	**SourFlv**	Sour Flavor	**FatAft**	Fat Aftertaste
Crm	Creaminess	**FatFlv**	Fat Flavor	**BitAft**	Bitter Aftertaste
Dns	Denseness	**BitFlv**	Bitterness Flavor	**AlkAft**	Alkaline Aftertaste
Ici	Iciness	**AlkFlv**	Alkaline Flavor	**SwtAft**	Sweet Aftertaste
				MlkAft	Milk Aftertaste

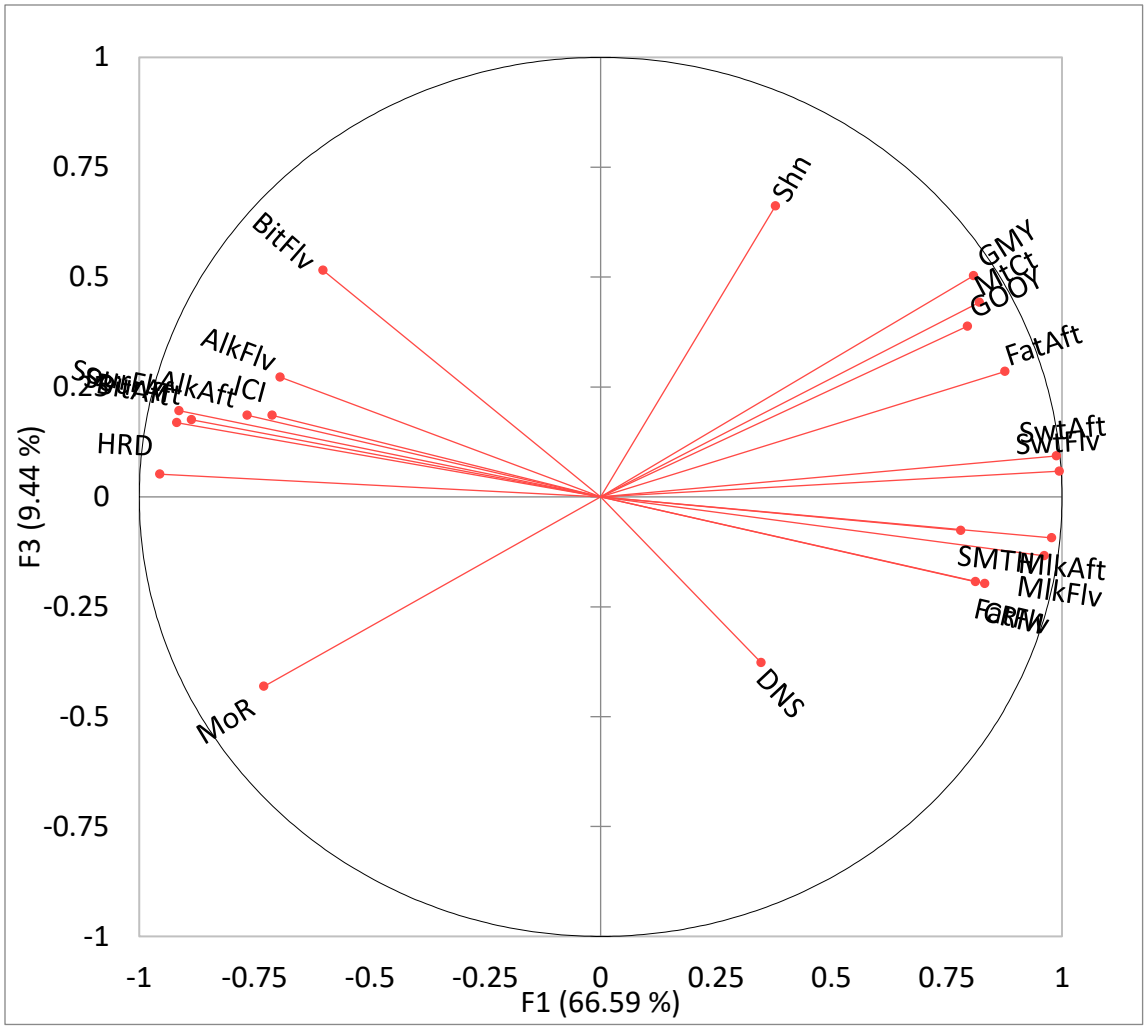


Figure 5-2 Principal component analysis of 22 attributes for seven frozen desserts on PC I and PC III (Correlation-Pearson model)

Parenthesis denotes the percent explained by the corresponding PC dimensions					
Attribute Code:					
Shn	Sheen	**Smth**	Smoothness	**SwtFlv**	Sweet Flavor
Gooy	Gooeyness	**Gmy**	Gumminess	**MlkFlv**	Milk Flavor
Hrd	Hardness	**MtCt**	Mouth Coating	**SourAft**	Sour Aftertaste
Mor	Rate of Melt	**SourFlv**	Sour Flavor	**FatAft**	Fat Aftertaste
Crm	Creaminess	**FatFlv**	Fat Flavor	**BitAft**	Bitter Aftertaste

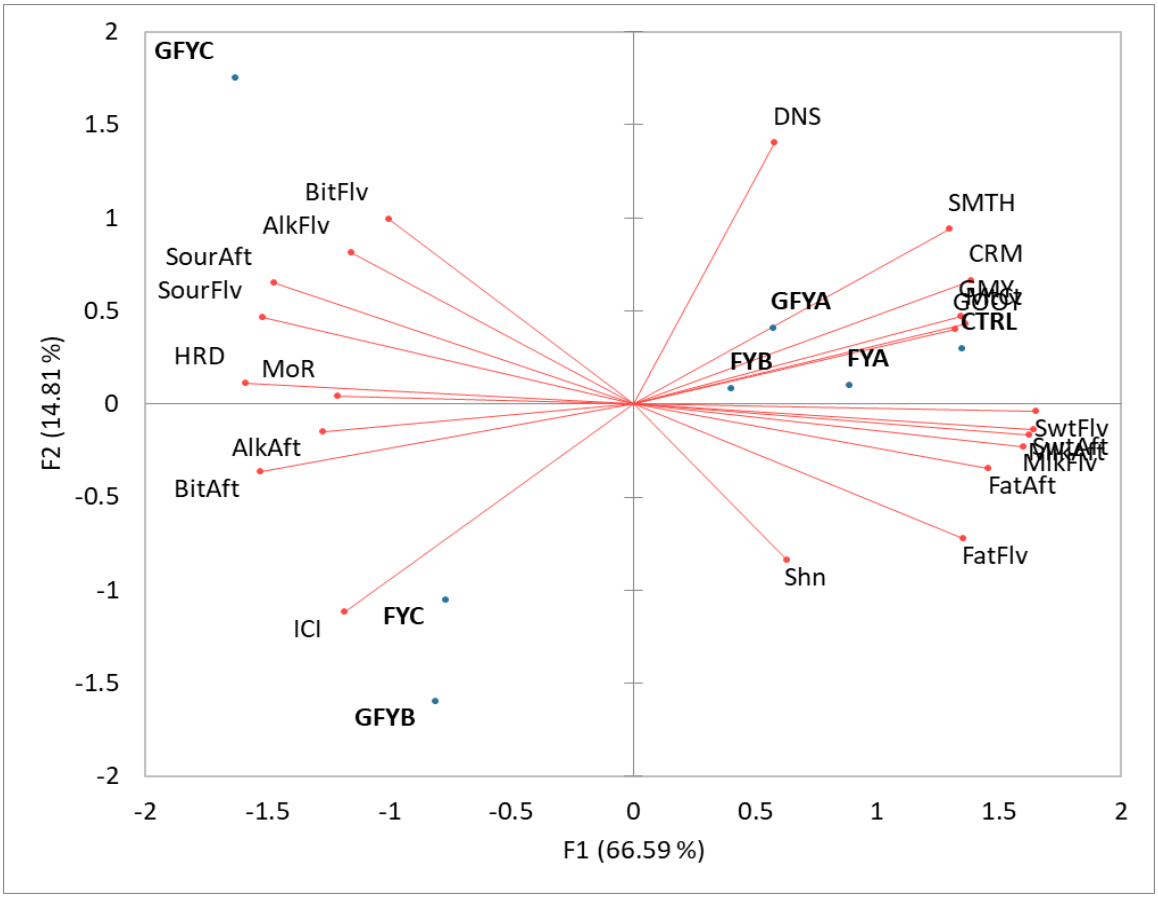


Figure 5-3 Principal component analysis of seven frozen desserts with sensory attributes on PC I and PC II (Correlation-Pearson model)

Parenthesis denotes the percent explained by the corresponding PC dimensions			
Attribute Code:			
Shn	Sheen	**FatFlv**	Fat Flavor
Gooy	Gooeyness	**BitFlv**	Bitterness Flavor
Hrd	Hardness	**AlkFlv**	Alkaline Flavor
Mor	Rate of Melt	**SwtFlv**	Sweet Flavor
Crm	Creaminess	**MlkFlv**	Milk Flavor
Dns	Denseness	**SourAft**	Sour Aftertaste
Ici	Iciness	**FatAft**	Fat Aftertaste
Smth	Smoothness	**BitAft**	Bitter Aftertaste
Gmy	Gumminess	**AlkAft**	Alkaline Aftertaste
MtCt	Mouth Coating	**SwtAft**	Sweet Aftertaste
SourFlv	Sour Flavor	**MlkAft**	Milk Aftertaste

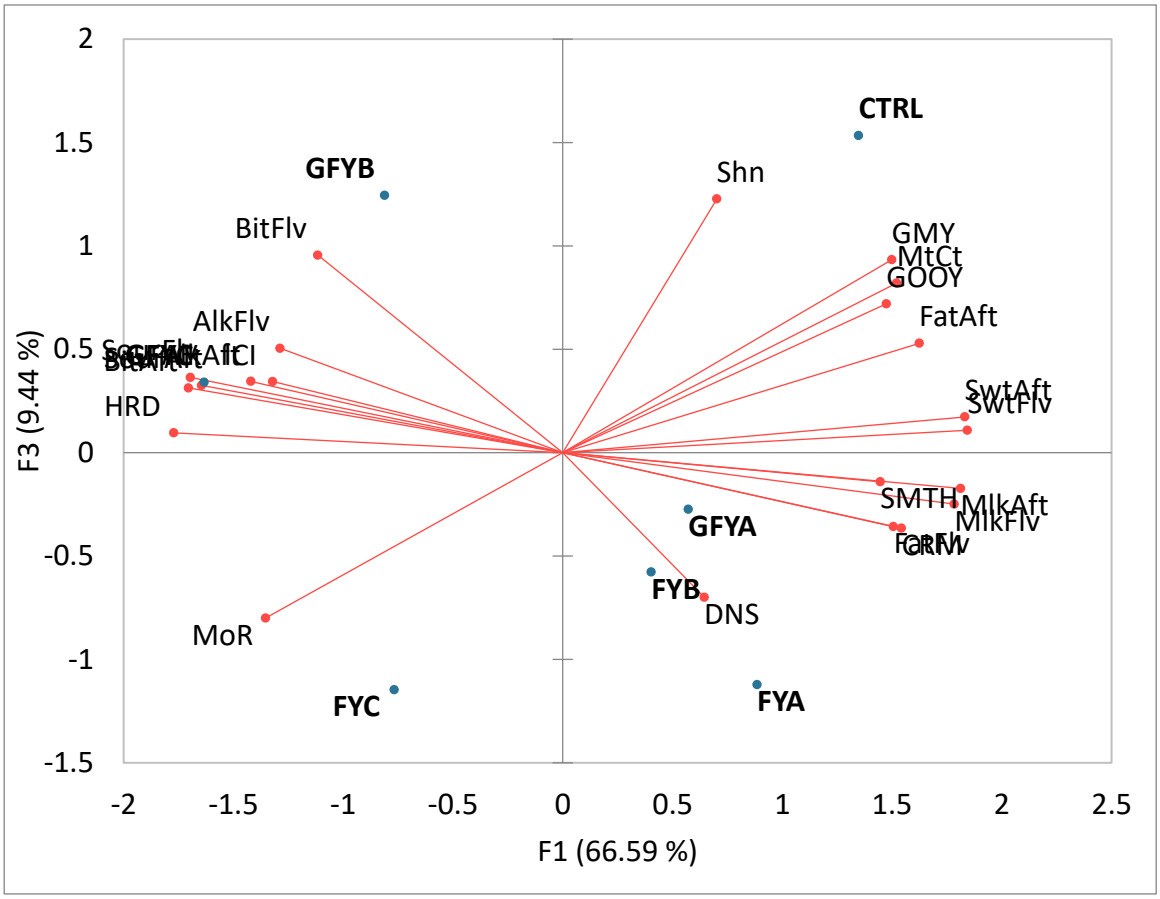


Figure 5-4 Principal component analysis of seven frozen desserts with sensory attributes on PC I and PC III (Correlation-Pearson model)

Parenthesis denotes the percent explained by the corresponding PC dimensions			
Attribute Code:			
Shn	Sheen	**FatFlv**	Fat Flavor
Gooy	Gooeyness	**BitFlv**	Bitterness Flavor
Hrd	Hardness	**AlkFlv**	Alkaline Flavor
Mor	Rate of Melt	**SwtFlv**	Sweet Flavor
Crm	Creaminess	**MlkFlv**	Milk Flavor
Dns	Denseness	**SourAft**	Sour Aftertaste
Ici	Iciness	**FatAft**	Fat Aftertaste
Smth	Smoothness	**BitAft**	Bitter Aftertaste
Gmy	Gumminess	**AlkAft**	Alkaline Aftertaste
MtCt	Mouth Coating	**SwtAft**	Sweet Aftertaste
SourFlv	Sour Flavor	**MlkAft**	Milk Aftertaste

5.4.5 Cluster analysis (CA)

The dendrogram obtained from agglomerative hierarchical cluster analysis, which included appearance, scoopability, texture, flavor and aftertaste attributes, showed the sensory characteristics as reflected by the logistics model parameters and identified distinct clusters (Figure 5-5). The descriptive data was centered and reduced with the XLSTAT software to avoid having a scaling effect on group creation. In addition, the automatic truncation option also was marked to show the groups and to decide when to stop aggregating observations. In Figure 5-5, the vertical distances indicated dissimilarity between clusters as measured by the Euclidean linkage distance between frozen dessert products.

Two distinctly dissimilar clusters were seen: cluster one consists of the control ice cream, FYA, FYB, and GFYA, while cluster two consists of FYC, GFYB, and GFYC. After reviewing the cluster results in tandem with the mixed-ANOVA and PCA model information, the two generated clusters were classified principally by several significant attributes, including: *sweet flavor*, *milk flavor*, *fat flavor*, *sweet aftertaste*, *fat milk aftertaste*, *fat aftertaste*, *creaminess*, *gumminess*, *mouth coating*, *hardness*, *bitter aftertaste*, *sour flavor*, *sour aftertaste*, and *alkaline aftertaste*, *smoothness*, *bitter flavor*, and *creaminess*. While some treatments expressed, on average, higher intensity ratings of a combination of these attributes, they also expressed low intensity ratings for others. For example, treatments in cluster one had a high intensity in *gooeyness*, *creaminess*, *smoothness*, *gumminess*, *mouth coating*, *fat flavor*, *sweet flavor*, *milk flavor* and their respective aftertastes, but also demonstrated low intensities in regard to *hardness*, *bitter flavor*, *sour flavor, and iciness*.

The initial two clusters were subdivided further by the dotted line which represented the automatic truncation. Cluster one was subdivided further into two more clusters. The control ice cream spilt off onto its own group while the FYA, FYB, and GFYA treatments grouped into their own cluster in which GFYA separated into another sub-cluster by itself. The sub-cluster of products containing low concentrations of yogurt demonstrated slightly lower intensities in the attributes described in cluster one and demonstrated higher intensities in hardness, iciness, and sourness flavor. Products in cluster two have a high intensity in *iciness*, *hardness*, and *sourness*. Cluster two was subdivided further into two more clusters. GFYC spilt off onto its own group while the FYC and GFYB treatments were grouped into their own cluster. The GFYC treatment demonstrated a significantly higher intensity of *hardness* and *sour flavor* compared to other products within cluster 2 and all other products in the study.

In summary, a combination of flavor and texture attributes were used in the classification of frozen dessert treatments with various yogurt types and concentrations. *Sweet*, *fat*, *milky*, and *sour* flavors, and their respective aftertaste – as well as *iciness* and *hardness* – are the important attributes to determine similarity. The control ice cream product was the sweetest product of all treatments, and it usually had a significantly positive correlation with *milky* and *fat* flavors; It also demonstrated the lowest intensities for *iciness* and *hardness* among the treatments. For taste perception, the control ice cream is close to FYA, FYB, and GFYA, but these treatments demonstrate less intense *sweet*, *fat*, and *milky* flavor attributes compared to the control ice cream due to the addition of yogurt. These treatments also demonstrated a slight increase in *hardness*, *sour flavor*, and

iciness. Clearly, the results are significantly similar to from the conclusions drawn from the PCA and mixed-model ANOVA.

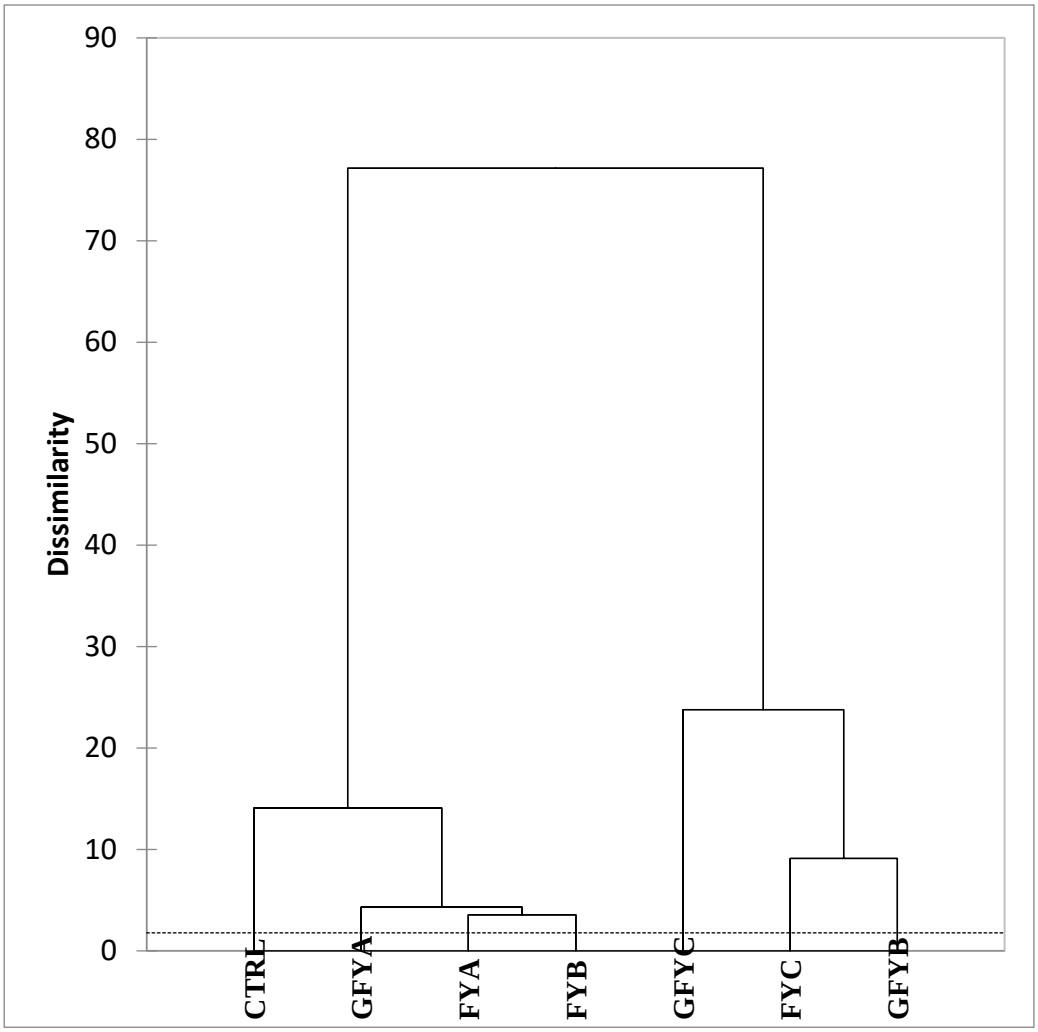


Figure 5-5 Cluster Analysis of seven frozen dessert Samples including 22 attributes categorized by appearance, scoopability, texture, flavor and aftertaste

Product Code:	
CTRL	Control Ice cream (no yogurt added)
FYA	90% ice cream/ 10% regular yogurt
FYB	85% ice cream/ 15% regular yogurt
FYC	80% ice cream/ 20% regular yogurt
GFYA	90% Ice cream/ 10% Greek yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

5.6 Conclusion

In this study, seven frozen dessert formulations were generated to understand the associations among regular set yogurt and Greek-style yogurt as ingredients in frozen dessert products. The descriptive analysis conducted showed that more than half of the flavor and texture attributes developed had significant differences across the tested products. The control ice cream and GFYC treatments held the highest intensity for most of the attributes with high significant differences. PCA indicated that the control ice cream had a high intensity in *sheen*, *gooeyness*, *creaminess*, *denseness*, *smoothness*, *gumminess*, *mouth coating*, *fat flavor*, *sweet flavor*, *milk flavor*, *fat aftertaste*, *sweet aftertaste*, and *milk aftertaste*. The cluster analysis demonstrated that the intensity of *sweet flavor*, *fat flavor*, *milky flavor*, *sour flavor*, *hardness*, and *iciness* attributes was a determinant in dissimilarity of taste among the tested products.

CHAPTER 6

Consumer Sensory Analysis of Low-Fat Frozen Desserts Containing Strained Yogurt

6.1 Introduction

Across the globe, consumers tend to purchase ice cream products based on taste, diversity of formulations, health benefits (low calories) and price (El-Nagar and others 2002; Peres and others 2018). Despite the expanding market for ice cream, developed countries such as the United States have decreased their consumption of frozen desserts containing high concentrations of sugar and fats and prefer low-caloric products, such as frozen yogurt and dairy-alternative desserts (Insight 2020). Although there is increased awareness of the consumers regarding health and nutrition related issues, consumer's demands for healthier products provides a unique challenge for the ice cream industry to develop frozen dessert products of high quality that meets consumer acceptance (Liou 2006; Soukoulis and others 2014).

According to Goff and Hartel (2013), the two factors that affect consumers' impression of ice creams are the body composition (e.g. fat, overrun, total solids, flavors, etc.) and their labeling (e.g. packaging and advertising). Of these factors, the condition of the dairy ingredients, flavors, freezing, and storage conditions are important in developing high quality frozen desserts (Guinard and Mazzucchelli 1996). Although there are standard practices for developing healthier food products by reducing fat, sugar, and salt concentrations, such changes often produce unacceptable flavors in dairy products (Biguzzi and others 2014). Even though alternative sugars have been studied to

preserve the sensory characteristics of sucrose (Ozdemir and others 2015; Palazzo and others 2011), Peres and others (2018) demonstrated that use of stevia provided undesirable attributes (e.g. bitter flavor and bitter aftertaste) in chocolate ice creams compared to sucralose, and the combination of vegetable proteins and alternative sweeteners in ice creams also reduced their acceptance among consumers. Guinard and others (1994) discovered that panelists had significantly different degree of liking scores of ice cream samples, preferring products with the lowest acidity. For frozen yogurt, Soukoulis and Tzia (2008) demonstrated that indirect acidification (blending of plain acidified milk with ice cream mix) created a favorable texture compared to direct acidification (fermentation of ice cream mix with starter culture). The application of various fibers, such as Glucagel® and inulin, to frozen yogurts provided a mixed consumer reception based on the overall stickiness and viscosity of the product (Frank 2014).

Greek yogurt was chosen for this study because of its increasing popularity. Although the product has become the flagship of the dairy industry occupying more space on market shelves, there are not many reports on its sensory profiling and consumer perception. Information about product formulation aligned with consumer preferences can help with product optimization and increase the competitiveness in today's competitive global market (Esmerino and others 2017). According to Amaral and others (2020), despite significant differences in appearance and texture, Greek yogurt products with added sucralose, araticum (Annona crassiflora) and mangaba (Hancornia speciosa) were overall accepted by consumers. Atamian and others (2014) have shown that milk with various fat concentrations significantly affect Greek yogurt products, with

full-fat yogurts being preferred the most. In a study involving the addition of date powder into Greek yogurt to improve textural and antioxidant capacity, the additional ingredient was significantly preferred based on degree of overall liking, flavor, and texture factors (Jrad and others 2019).

Developing new products involves understanding the underlying attributes that contribute to consumers' acceptance or rejection of a product and how those attributes might be modified to increase acceptability. Multivariate statistical techniques, such as preference mapping and Check-all-that-apply (CATA), aim to solve this dilemma by combining descriptive sensory attributes and consumer hedonic data so that relationships between different sensory and physical properties of foods can be understood (Esmerino and others 2017). These techniques are used to explore consumers' attitude and preference patterns and take that information into account for creating new products or improving existing products (Cavitt and others 2004). The goal of this study was to formulate a frozen dessert with Greek yogurt and to compare its acceptance among consumers to common and typical frozen desserts found in the marketplace. These findings will help in understanding whether the addition of Greek yogurt to ice cream products will meet consumer demands.

6.2. Materials & methods

6.2.1 Materials

Fat-free ice cream mix (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL) was used in the study. Set yogurt and Greek yogurt was created with Prairie Farms fat free skim milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL) and Yogourmet freeze-dried yogurt starter (Yogourmet, Canada). This starter culture contains

skim milk powder, sucrose, and active bacterial cultures (*L. bulgaricus, S. thermophilus, L. acidophilus*).

6.2.2 Frozen dessert manufacture

Frozen yogurt treatments were prepared according to the method by Li and others (1997). According to Marshall and others (2003), at least 5% of the weight of the total mix should be yogurt. We used six frozen dessert treatments: three frozen yogurts containing 10, 15, and 20% added set yogurt, and three frozen yogurts containing 10, 15, and 20% added Greek Style yogurt. Frozen yogurt mixes were prepared in 2.5-gallon batches. Yogurts were manually stirred with their respective ice cream mixes prior to freezing using a stainless-steel spiral mixer (Warner, China) in order to breakdown the gels formed during incubation for three minutes. Table 3-1 describes the specific formulation of each product. The stirred frozen yogurt mixes with a semi-liquid consistency were frozen in an ice cream freezing machine (Taylor 0702, Taylor Co. Rockton, IL) in 2.5-gallon batches for approximately 10-20 minutes depending on the treatment. The frozen yogurt batches were packed into and tightly sealed in two-ounce portion cups (Eco-Products, Boulder, CO). Containers were labeled and then placed in a freezer at -40 °C for hardening and storage.

6.2.3 Consumer tests

The consumer study was advertised by posting physical flyers and sending announcements via the email distribution list of the College of Agriculture, Food, and Natural Resources (CAFNR) at the University of Missouri – Columbia and the general email distribution list advertised to all students attending the same university after approval by the Campus's Institutional Review Board. A total of 101 volunteers

participated in the consumer study, which was held over the course two weeks from 9:00 a.m. to 5:00 p.m. No more than three panelists were allowed to participate in the study at once to accommodate the Campus's social distancing policy due to COVID-19. When consumer panels arrived at the sensory lab, they were provided and asked to read the consent form (Appendix G) if they were willing to participate in the study. Additional explanations were given when requested by potential panelists. Consumer evaluation of the frozen dessert samples was conducted in isolated booths illuminated with incandescent light, and evaluations were conducted using paper ballots. Seven yogurt flavored samples frozen desserts coded with three-digit random numbers were evaluated using a hedonic test (acceptance) and then a ranking test (preference). Panelists evaluated each of the samples monadically (one after the other) and indicated the degree of liking of flavor (DOF), texture (DOT), appearance (DOA), as well as overall liking (DOL), using a nine-point hedonic scale where 1 = dislike extremely to 9 = like extremely (Peryam and Pilgrim 1957) (Appendix G).

Panelists were asked to cleanse their palates by chewing a small piece of an unsalted cracker and by rinsing with water at the beginning of the test and between samples to minimize carry-over and fatigue effects. After evaluating each sample and answering the provided questionnaire, panelists were instructed to rank each sample on a scale of 1-7, where one represents "the most favorite" and seven represents "the least favorite." Panelists were encouraged to retaste samples for the ranking test. Tied rankings were not allowed.

6.3 Experimental design and data analysis

A 7 X 7 Williams modified Latin-square design was used to determine the serving order for all panelists was generated by the R statistical program (Næs 1996). When the number of treatments is odd (as in this case), balance in a single Latin-square is not possible. By duplicating the design – creating a 7 X 14 latin-square – positional and pairwise balance can be achieved for the first-order carryover effect. Since we recruited 101 consumers to taste seven samples for each of their respective sessions, 101 separate slots were needed in the design. As the 7 x 14 Williams design has only 14 slots for each panelist, the full design was repeated 7 times. Some slots were repeated as needed to fill up the additional slots. The distribution order of treatments to each panelist can be found in Appendix E.

A mixed model analysis of variance (ANOVA) was performed to the ratings of DOL, DOF, DOT, and DOA in order to determine significant differences among the products at $p < 0.05$ (Appendix H). Panelist was considered a random effect in the model. A correlation matrix was created to explore relationships among the ratings of each product. Wilcoxon rank sum (Krsukal-Wallis) test and Friedman's test were used to evaluate significant differences in the preference ranking of products by the R statistical software. Internal preference mapping, based on the PCA performed on consumer acceptability scores with the products as observations and consumers as variables, was analyzed using XLSTAT-2020 (XLSTAT, Addinsoft, USA). External preference mapping using the result of the agglomerate hierarchical clustering (y-data set) and principal component analysis (PCA) (X-data set) was conducted by XLSTAT-2020

(XLSTAT, Addinsoft, USA) and the SensorMineR package within the RStudio statistical program (Husson and others 2020).

Table 6-1 Frozen dessert formulations per 100g basis for products containing various yogurt types

Ingredients / Sample	Ice Cream Mix[a]	Set Yogurt[b]	Greek Yogurt[c]
Control (No yogurt added)	100	0	0
FYA (90%Ice cream mix; 10% set yogurt)	90	10	0
FYB (85%Ice cream mix; 15% set yogurt)	85	15	0
FYC (80%Ice cream mix; 20% set yogurt)	80	20	0
GFYA (90%Ice cream mix; 10% Greek yogurt)	90	0	10
GFYB (85%Ice cream mix; 15% Greek yogurt)	85	0	15
GFYC (80%Ice cream mix; 20% Greek yogurt)	80	0	20

[a] Fat-free ice cream mix (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

[b] Developed with fat-free milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

[c] Developed with fat-free milk (Prairie Farms Dairy, Prairie Farms Inc., Edwardsville, IL)

6.4 Results & discussions

6.4.1 Consumer acceptance for hedonic test

One hundred and one consumers evaluated seven frozen dessert samples using a nine-point hedonic scale (1 = like extremely to 9 = dislike extremely). Based on the questionnaire information, the demographics of the panelists consisted of 35% of men, 65% of women, 60% of panelists who were approximately 18-30 years of age, and 40% of panelists who were above 30 years of age. From this group of panelists, it was discovered that 55% of them consumed frozen desserts at least once a month, 39% of them consume yogurt at least once a month, and 83% of them prefer ice creams over low-fat ice creams and frozen yogurt products (Appendix H).

A mixed model ANOVA method was used to analyze the hedonic data set to determine if there were significant differences in the degree of overall liking (DOL), overall flavor (DOF), overall appearance (DOA) and overall texture (DOT) among products (Table 6-2). All products showed significant differences among DOL ($P<0.001$), DOF ($P<0.001$), DOA ($P<0.01$) and DOT ($P<0.001$) at the $P<0.05$ significance level. The DOL factor had the highest positive significant correlation with that of DOF according to the Pearson coefficient's result of the correlation matrix (0.91; P-value=0) (Table 6-3). In other words, the flavor of the frozen dessert products is most likely more important than their texture and appearance in regard to determining consumer acceptability of the provided products.

Guinard and Mazzucchelli (1996) indicated that overall liking was composed of liking the flavor and texture in ice creams. In this study, consumer acceptance of the seven frozen desserts ranged on average between "like moderately" and "neither like nor

dislike”. The control ice cream had the highest least squares mean (LS-mean) DOL hedonic rating of 7.38 and GFYC had the lowest LS-mean of 5.3, most likely because it also had the lowest DOF rating (Table 6-4). The control ice cream had a significantly higher acceptability rating compared to the FYC, GFYB and GFYC products. There were significant differences among the DOF rankings of the control ice cream and all products containing Greek yogurt; However, GFYA showed a significantly higher rating compared to GFYC. There were similar significant differences among the DOA and DOT rankings where the control ice cream received a significantly higher rating than GFYB. The results show that the addition of Greek-yogurt at high concentrations did make significant differences to the degree of liking and flavor, whereas the liking of appearance and texture did not differ significantly.

Table 6-2 F-value and significance of the effects of source of variation (product) for the mixed-model analysis of variance for seven frozen dessert samples

Effect of Product	DF	Sum Sq	Mean Sq	F- Value	Pr > F	Significance
DOL	6	191.11	31.852	12.84	9.73e-08	***
DOF	6	245.61	40.935	14.779	1.725e-08	***
DOA	6	44.554	7.4256	3.5659	0.001737	**
DOT	6	115.89	19.314	7.2121	3.788e-05	***

*** ** *** Significant at P<0.05, 0.01, and 0.001, respectively**

DOL = degree of liking

DOF = degree of flavor

DOA = degree of appearance

DOT = degree of texture

Table 6-3 Flattened correlation matrix of hedonic data containing the correlation coefficient values (Pearson method) of the overall liking (DOL), Liking of flavor (DOF), liking of appearance (DOA) and liking of texture (DOT)

Variable A	Variable B	Correlation Coefficient	P-value
DOL	**DOF**	0.9125813	0
DOL	**DOA**	0.5048410	0
DOF	**DOA**	0.4253459	0
DOL	**DOT**	0.6765694	0
DOF	**DOT**	0.5520567	0

Table 6-4 LS mean score of overall liking, overall flavor, overall texture and overall appearance derived from a mixed-model ANOVA for consumer hedonic data

Product	LS mean score			
	Overall Flavor	**Overall Appearance**	**Overall Texture**	**Overall Liking**
CTRL	7.44^{a}	6.83^{ab}	7.01^{a}	7.38^{a}
FYA	6.96^{ab}	7.08^{a}	7.37^{a}	7.11^{ab}
FYB	6.92^{ab}	6.91^{ab}	7.21^{a}	7.10^{ab}
FYC	6.27^{ab}	6.82^{ab}	6.66^{ab}	6.48^{bc}
GFYA	6.77^{bc}	6.97^{a}	7.12^{a}	6.81^{ab}
GFYB	5.59^{cd}	6.27^{b}	5.76^{b}	5.64^{c}
GFYC	5.29^{d}	6.57^{ab}	6.47^{ab}	5.63^{c}
There are no significant differences at $p<0.05$ among the samples with the same superscript letter within a column.				

6.4.2. Consumer preference

Preference rankings were analyzed using Friedman's test and the Wilcoxon rank sum (Kruskal-Wallis) test by the XLSTAT software to evaluate significant differences in the preference ranking of products. The Kruskal-Wallis test, a non-parametric procedure, has been suggested for consumer preference tests (McKight and Najab 2010). The chi-square for the rank means, as performed by this test found significant differences at $P<0.05$ between the rank means ($p<0.0001$) (Table 6-5). The Friedman's test is a traditional method in handling the ranked data of sensory analysis and is a powerful tool for any data set (Lawless and Heymann 2010). The chi-square from the Friedman's test to calculate the ranks also showed significant differences among products ($p<0.0001$) and agrees with the Kruskal-Wallis test. The DOL ranking from the mixed-model ANOVA (Table 6-2) and the preference ranking tests (Table 6-6) show similar differences among consumer preferences. Regardless of the analysis, the control ice cream had a significantly higher acceptability rating compared to the GFYB and GFYC products. The Kruskal-Wallis test does show that there were no significant differences among the control ice cream, FYA and FYB products compared to the other two tests. In this study, consumer preference has a highly positive correlation with consumer acceptance for the seven products.

Table 6-5 Statistical results of Friedman test and Wilcoxon rank sum (Kruskal-Wallis test)

Statistical Test	Chi-square Value	Chi-square (Critical value)	DF	p-value	alpha
Friedman's test:	95.416	12.592	6	<0.0001	0.050
Kruskal-Wallis test / Two-tailed test:	110.202	12.592	6	<0.0001	0.050

Table 6-6 Analysis of consumer ranking data by Friedman test with the Nemenyi's procedure and Wilcoxon rank sum with the Kruskal-Wallis test

Product	N	Friedman Test Scores								Wilcoxon Test Scores	
		Frequency							Rank Total	Sum of Scores	Mean of Score
		1	2	3	4	5	6	7			
CTRL	101	30	21	11	15	8	9	7	306.500[a]	26003.500	257.460[a]
FYA	101	21	17	23	10	15	7	8	336.500[a]	28931.500	286.450[a]
FYB	101	11	24	19	18	15	9	5	352.000[ab]	30444.500	301.431[a]
FYC	101	13	12	12	14	12	20	18	364.000[ab]	31762.500	314.480[ab]
GFYA	101	14	16	19	21	14	11	6	434.500[bc]	38847.500	384.629[bc]
GFYB	101	5	5	8	14	21	20	28	516.500[c]	47043.500	465.777[c]
GFYC	101	6	6	9	10	16	25	29	518.000[c]	47245.000	467.772[c]

There are no significant differences at $p<0.05$ among the samples with the same superscript letter.

6.4.3. Internal preference mapping

Internal preference mapping, which is used on a set of samples, is based on a PCA method performed on a series of consumer scores, which are the variables, and the products, which are the observations, into a set of preference dimensions to determine consumer preference patterns and the differences among samples (Rousseau and others 2012). The preference map usually is a biplot of the observations (products) and the variables (consumers). In all of the internal maps generated, consumer preference was evenly distributed in the four quadrants of their respective maps (Figures 6-1, 6-2, 6-3, and 6-4). This means that either consumers could not discriminate the products by differences in flavor, appearance, and texture (Kruel 2004) or that consumers were more closely grouped around samples, which had higher intensities of certain attributes causing great variations in individual preference. Considering the significant results of the LS-means analysis, the second reason is the more likely one.

The first two dimensions of the internal preference map for the degree of the liking data accounted for 48% of total variance, with 32% of the variance explained in dimension 1 and 17.5% of the variance explained in dimension 2 (Figure 6-1). The internal preference map shows 58 of 101 (57.42%) consumers are located on the positive side of the Y-axis and 43 of 101 (42.57%) of the consumers are located on the negative side of the Y-axis. Among them, approximately 54 consumers (54.16%) had a high correlation with the control ice cream and 22 consumers (21.95%) preferred FYA. Some frozen desserts containing larger concentration of Greek-yogurt were clustered together on the negative Y-dimension. Approximately 40 consumers disliked the GFYB (17.88%) and GFYC (22.43%) products in the DOL map (Figure 6-1). Further analysis indicated

that about 58 consumers (57.45%) were considered important drivers in the determination of the DOL.

The DOF internal preference map showed similar trends with the DOL internal preference map in regard to similar significant variables and clusters in the model. The first two dimensions of the internal preference map for the degree of flavor data accounted for 49.45% of total variance, with 29.29% of the variance explained in dimension 1 and 20.16% of the variance explained in dimension 2 (Figure 6-2). The map shows 53 of 101 (52.47%) consumers are located on the positive side of the Y-axis and 48 of 101 (47.52%) of the consumers are located on the negative side of the Y-axis. Among them, approximately 41 consumers (41.74%) had a high correlation with the control ice cream and 27 consumers (26.27%) preferred FYA. Approximately 43 consumers disliked the flavor of GFYB (22.86%) and GFYC (20.28%) products in the DOF map. Further analysis indicated that about 61 consumers (60.39%) were considered important drivers in the determination of the DOL internal map. It can be concluded that a large portion of the consumers preferred all of the frozen dessert treatments, but the control ice cream and FYA are more preferred in comparison to treatments with larger concentrations of Greek-yogurt.

The DOA internal preference map contained all seven frozen dessert samples as active variables in the model. All samples containing yogurt were clustered together on the positive Y-dimension and the control ice cream and samples containing Greek-yogurt were clustered together on the negative Y-dimension. The first two dimensions of the internal preference map for the degree of flavor data accounted for 64.07% of total variance, with 53.01% of the variance explained in dimension 1 and 11.06% of the

variance explained in dimension 2 (Figure 6-3). The map shows 47 of 101 (46.53%) consumers are located on the positive side of the Y-axis and 54 of 101 (53.46%) of the consumers are located on the negative side of the Y-axis. All consumers were roughly loaded evenly across the first dimension. In the context of this specific map, this means that consumers could not discriminate the products by differences in appearance. Further analysis indicated that about 77 consumers (76.24%) were considered important drivers in the determination of the DOA internal map.

The DOT internal preference map produced two active variables in the model – FYC on the positive Y-dimension and GFYB on the negative Y-dimension. The first two dimensions of the internal preference map for the degree of flavor data accounted for 48.02% of total variance, with 33.17% of the variance explained in dimension 1 and 14.86% of the variance explained in dimension 2 (Figure 6-4). The internal preference map shows 52 of 101 (51.5%) of the consumers are located on the positive side of the Y-axis and 49 of 101 (48.5%) of the consumers are located on the negative side of the Y-axis. Among them, approximately 46 consumers (45.79%) had a high correlation with the FYC product, and 16 consumers (15.93%) disliked the GFYB product in the DOT map (Figure 6-1). Further analysis indicated that about 59 consumers (58.41%) were considered important drivers in the determination of the DOT internal map. As all consumers were roughly loaded evenly across the first dimension, it can be concluded that consumers preferred the texture of all of the various provided samples for their own uniqueness. Some consumers preferred denser, harder, and icier products similar to GFYB and GFYC while other consumers preferred the smooth, creamy and mouth coating aspects of FYB and FYC.

Kruel (2004) indicated that thickness, smoothness, gumminess, milky flavor aftertaste and mouth coating in ice cream products had a high correlation with positive consumer hedonic ratings. In addition, consumers most likely disliked icy and hardness attributes. In this study, the flavor attributes of the products clearly contribute to the overall degree of liking to the provided products in comparison to appearance and texture. However, some consumers in this study preferred icy and hard texture attributes in certain products compared to the smoother and creamier products. Most consumers can discriminate between flavor and texture differences among the samples but could not discriminate differences among the appearance among the products.

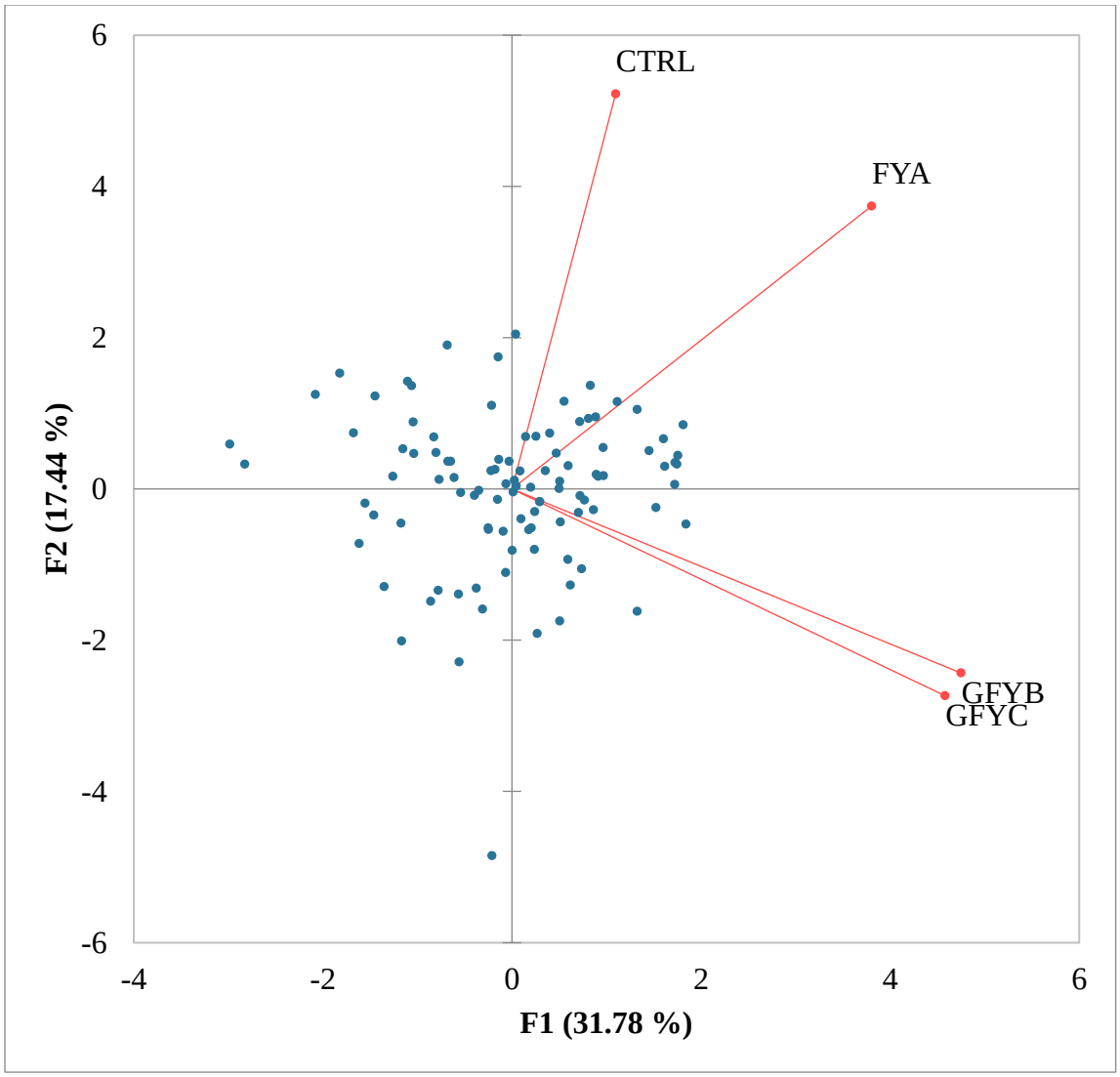


Figure 6-1 Internal preference mapping (Pearson Correlation) of overall degree of liking of seven frozen desserts for all consumer panels

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code (active variables):	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

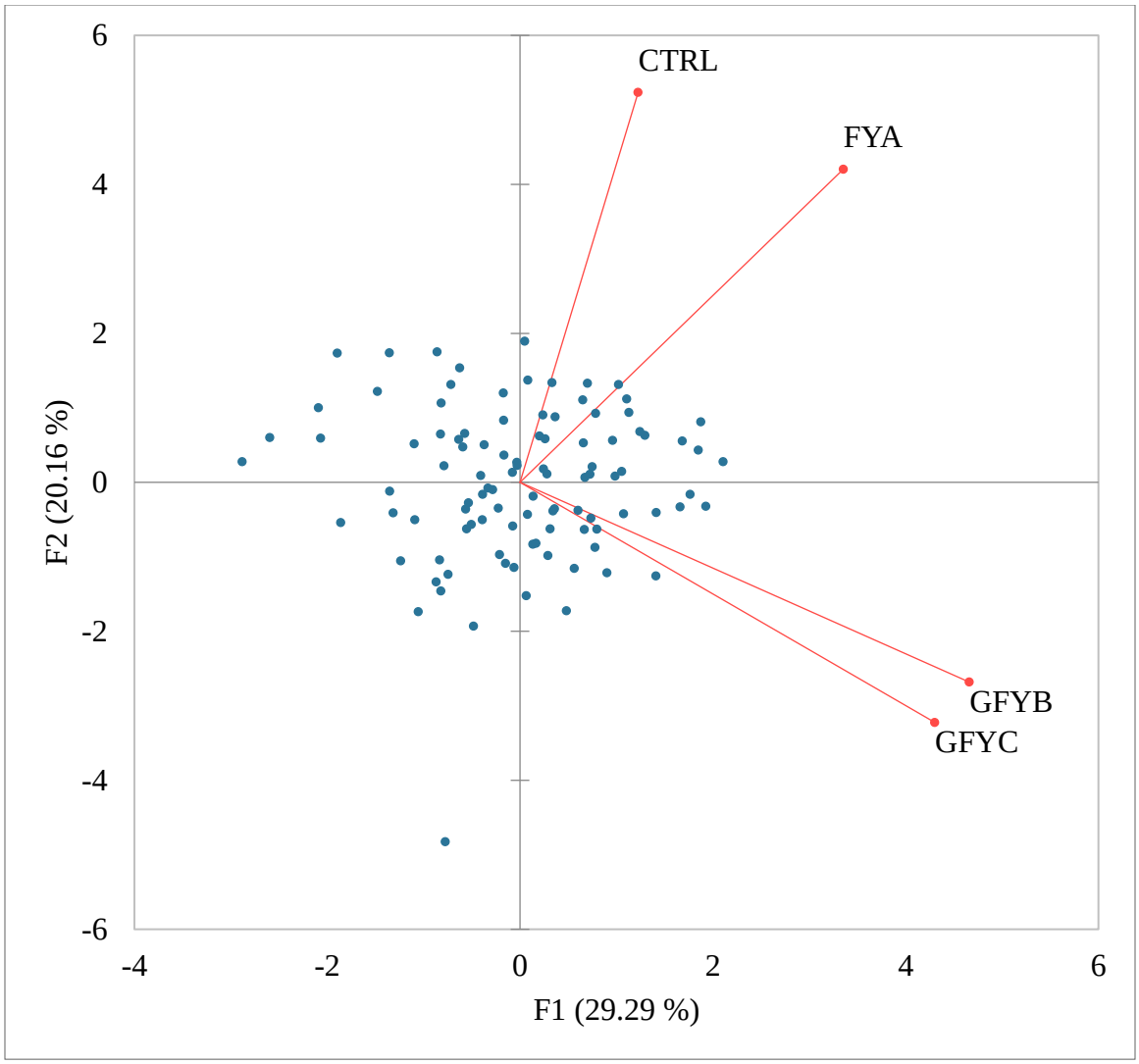


Figure 6-2 Internal preference mapping (Pearson Correlation) of overall degree of flavor liking of seven frozen desserts for all consumer panels

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code (active variables):	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

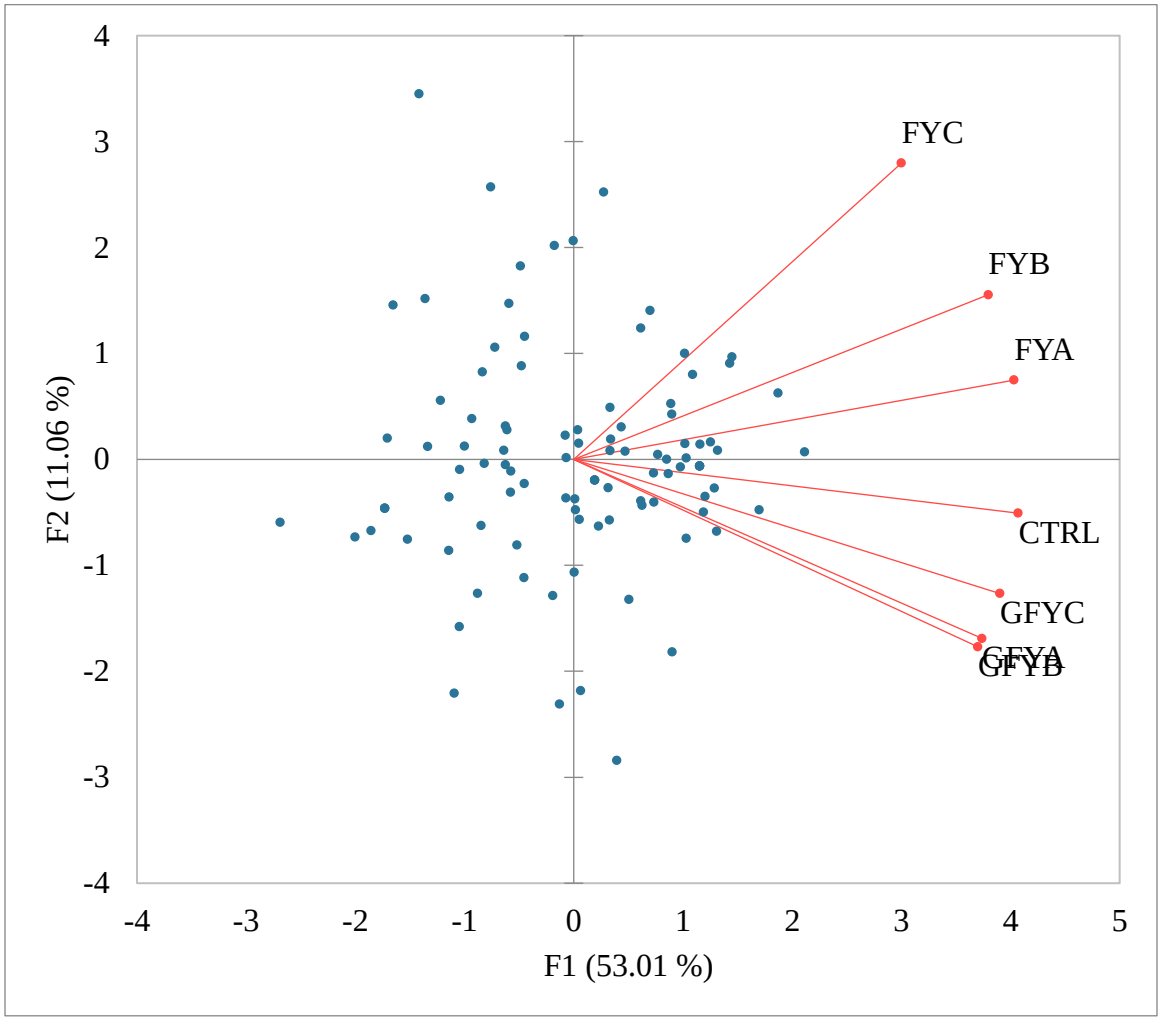


Figure 6-3 Internal preference mapping (Pearson Correlation) of overall degree of appearance liking of seven frozen desserts for all consumer panels

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code (active variables):	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
FYB	85% ice cream/ 15% regular yogurt
FYC	80% ice cream/ 20% regular yogurt
GFYA	90% Ice cream/ 10% Greek yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

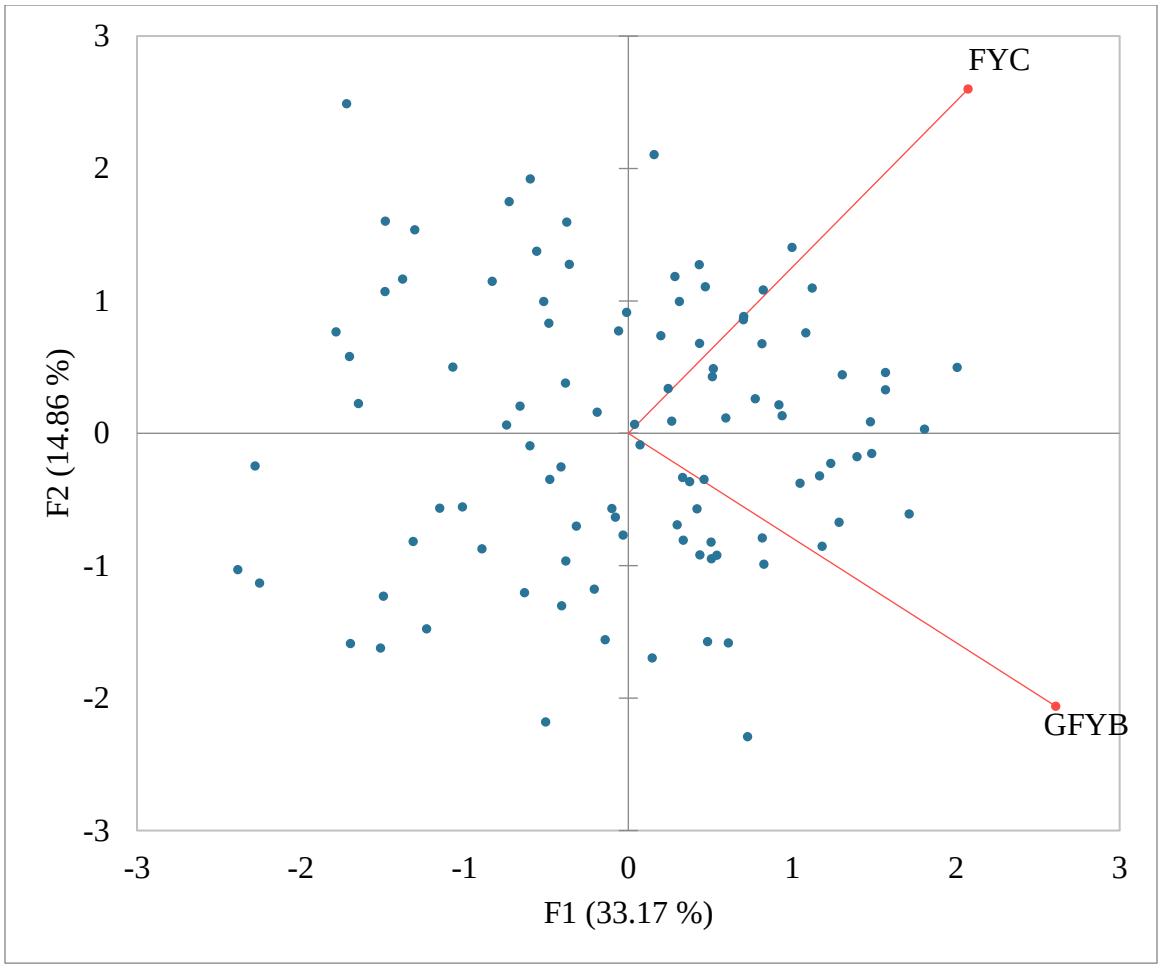


Figure 6-4 Internal preference mapping (Pearson Correlation) of overall degree of texture liking of seven frozen desserts for all consumer panels

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code (active variables):	
FYC	80% ice cream/ 20% regular yogurt
GFYB	85% ice cream/ 15% Greek yogurt

6.4.4 External preference mapping (XLSTAT)

External preference mapping (PREFMAP) allows relating consumer preferences with the sensory characteristics of products, as determined by a descriptive analysis. The method can help create or adapt products that will correspond to the consumer preference. PREFMAPs have three different models, including the circular preference, the elliptical preference, and the vector preference model. As the first two models require at least eight products, and this study only contained seven products, the vector preference model was chosen as it only requires a minimum of six products (Greenhoff and MacFie 1994). The vector model allows displaying the observations (consumer cluster) on a sensory map as vectors. The size of the vectors can be related to the R^2 of the model. That is to say that the longer the vector is, the better the underlying model. The first step for external preference mapping was to obtain the important characteristics of the products by running a Principal Component Analysis (PCA) or Generalized Procrustes Analysis (GPA). In this study, PCA was performed with the XLSTAT software because it can correlate the sensory attributes and products. The second step was to group the consumers in order to make the PREFMAP results easier to interpret. The hedonic ratings by the 101 consumers were computed by agglomerative hierarchical clustering (AHC) using XLSTAT software. Clustering methods were utilized in R to determine the proper amounts of clusters to employ for each respective AHC. As a result, three clusters were grouped for the DOL PREFMAP based on clustering methods; two clusters were grouped for the DOF, DOA and DOT PREFMAPs.

Figure 6-5 summarizes the PREFMAP for the degree of overall liking using the factor scores of the seven frozen desserts from the PCA on the X-axis and the ratings for

three clusters from the AHC on the Y-axis, both of which accounted for 81.4% of the total variance. The result showed the vector model is well fitted for cluster 1 ($R^2 = 0.877$, $p = 0.015$). Cluster 2 and cluster 3 are also fitted for vector models, but they are not significant to the overall PREFMAP. The consumers grouped in cluster 1 (36.44% of consumers) preferred the control ice cream product and disliked the frozen desserts with large concentrations of yogurt – regardless of the type of yogurt. The preference orders of consumers in cluster 1 are as follows: CTRL> FYA> GFYA> FYB> FYC> GFYB> GFYC. Clusters 2 (28.08% of consumers) and 3 (35.47% of consumers) show similar attributes to cluster 1. However, cluster 3 focuses only on the textural attributes rather than a combination of the texture and flavor attributes.

The PREFMAP for the flavor characteristics with the DOF of frozen desserts, shown in figure 6-6, accounted for 89.62% of the total variance for two clusters. The result showed cluster 1 (48.35% of consumers) is well fitted for the vector model ($R^2 = 0.816$, $p = 0.034$). Cluster 2 (51.64%) of consumers) was also found to be well fitted for the vector model ($R^2 = 0.930$, $p = 0.005$). The consumers grouped in both clusters shared similar preferences to the PREFMAP for the degree of liking – they preferred the control ice cream product and disliked the frozen desserts with large concentrations of yogurt. As for overall liking, the preference orders of consumers in both are as follows: CTRL> FYA> GFYA> FYB> FYC> GFYB> GFYC. The PREFMAP for the flavor characteristics was not different from the mixed-model ANOVA. It could be speculated that consumers dislike products containing high concentrations of sour, bitter, and alkaline flavors.

Figure 6-7 summarizes the PREFMAP for the appearance characteristics with DOA which accounted for 99% of the total variance. The result showed the vector model is well fitted for cluster 2 ($R^2 = 0.777$, $p = 0.050$). Cluster 1 (46.15% of consumers) was also best suited for vector models but was not significant to the overall model. The GFYC product was most preferred in terms of appearance within the first cluster; The preference orders of consumers in cluster 1 are as follows: GFYC> FYA> FYC> FYB> GFYA> CTRL> GFYB>. Clusters 2 (54.8% of consumers) show similar preferences and preferences orders as described in the PREFMAP for the overall liking of products. It could be inferred that some consumers preferred the appearance of products containing high concentrations of yogurts while others preferred appearance products that resemble a regular ice cream.

The PREFMAP for the texture characteristics with the DOT of frozen desserts is shown in figure 6-8 accounted for 89.32% of the total variance for two clusters. The result showed cluster 2 (56.16% of consumers) is well fitted for the vector model ($R^2 = 0.79$, $p = 0.044$). Cluster 1 was also fitted for the vector model, but it was not significant to the overall PREFMAP. Both clusters preferred frozen dessert samples that have gooeyness, creaminess, denseness, smoothness, gumminess, mouth coating. The consumers grouped in both clusters shared somewhat similar preferences to the PREFMAP for the degree of liking; consumers in cluster 1 had more of a preference for the GFYA product while consumers in the cluster 2 preferred the control ice cream product. The PREFMAP for the flavor characteristics was not different from the same analysis in the mixed-model ANOVA. It could be inferred that some consumers preferred the texture of products containing low concentrations of yogurt that have the texture of a

smoother and creamy product while others preferred products that are harder in texture. In essence, consumers would prefer products that contain the extreme of a given textural attribute, as some the GFYC product is accepted by most consumers from a textural standpoint.

Overall, PREFMAP is a powerful tool compared with other multivariate statistical methods. It was not difficult for consumers to compare the relationships between sensory characteristics and DOL as consumers easily discriminated differences in frozen dessert samples. Using several preference techniques, it can be concluded that DOL, as perceived by consumers, is positively correlated with the control ice cream, FYA, FYB, and GFYA. In other words, the most influential factors for DOL were related to flavor and texture. PREFMAPs with contour plots demonstrated the percentage of the population that preferred specific treatments in conjunction with the cluster results (Appendix H).

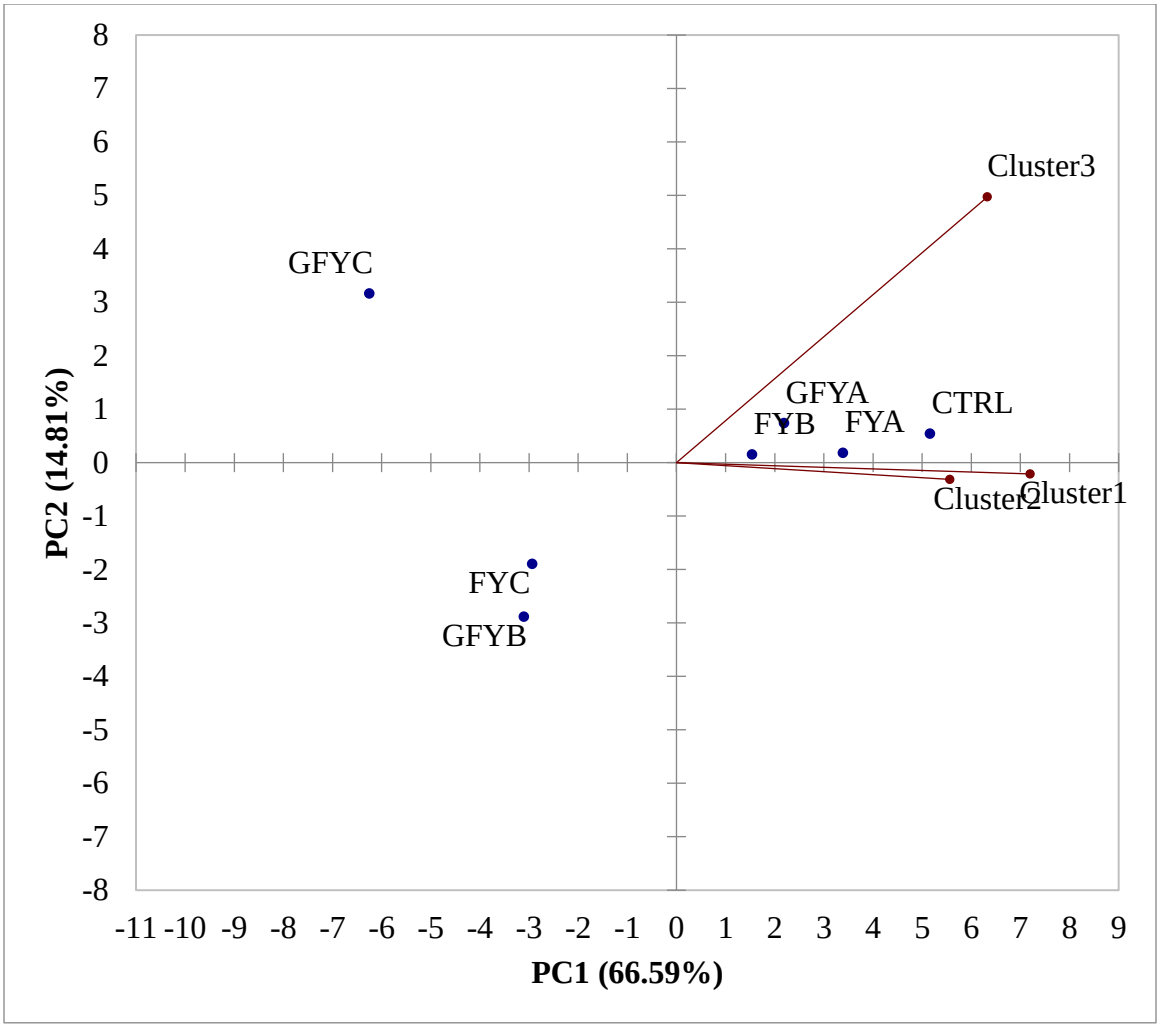


Figure 6-5 External preference mapping of consumer perception of overall liking of seven frozen desserts using descriptive data and hedonic data

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code:	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
FYB	85% ice cream/ 15% regular yogurt
FYC	80% ice cream/ 20% regular yogurt
GFYA	90% Ice cream/ 10% Greek yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

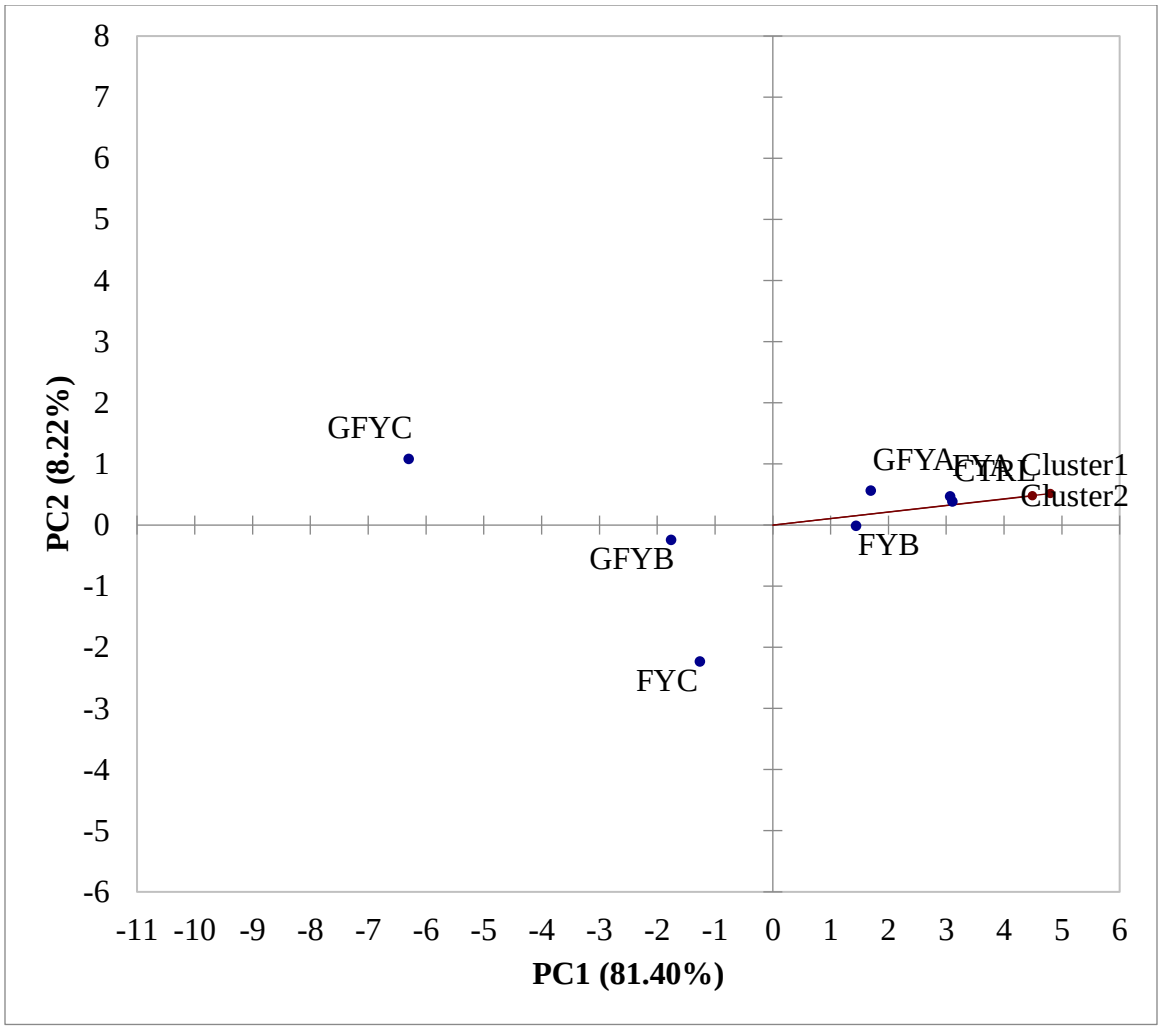


Figure 6-6 External preference mapping of consumer perception of flavor liking of seven frozen desserts using descriptive data and hedonic data

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code:	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
FYB	85% ice cream/ 15% regular yogurt
FYC	80% ice cream/ 20% regular yogurt
GFYA	90% Ice cream/ 10% Greek yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

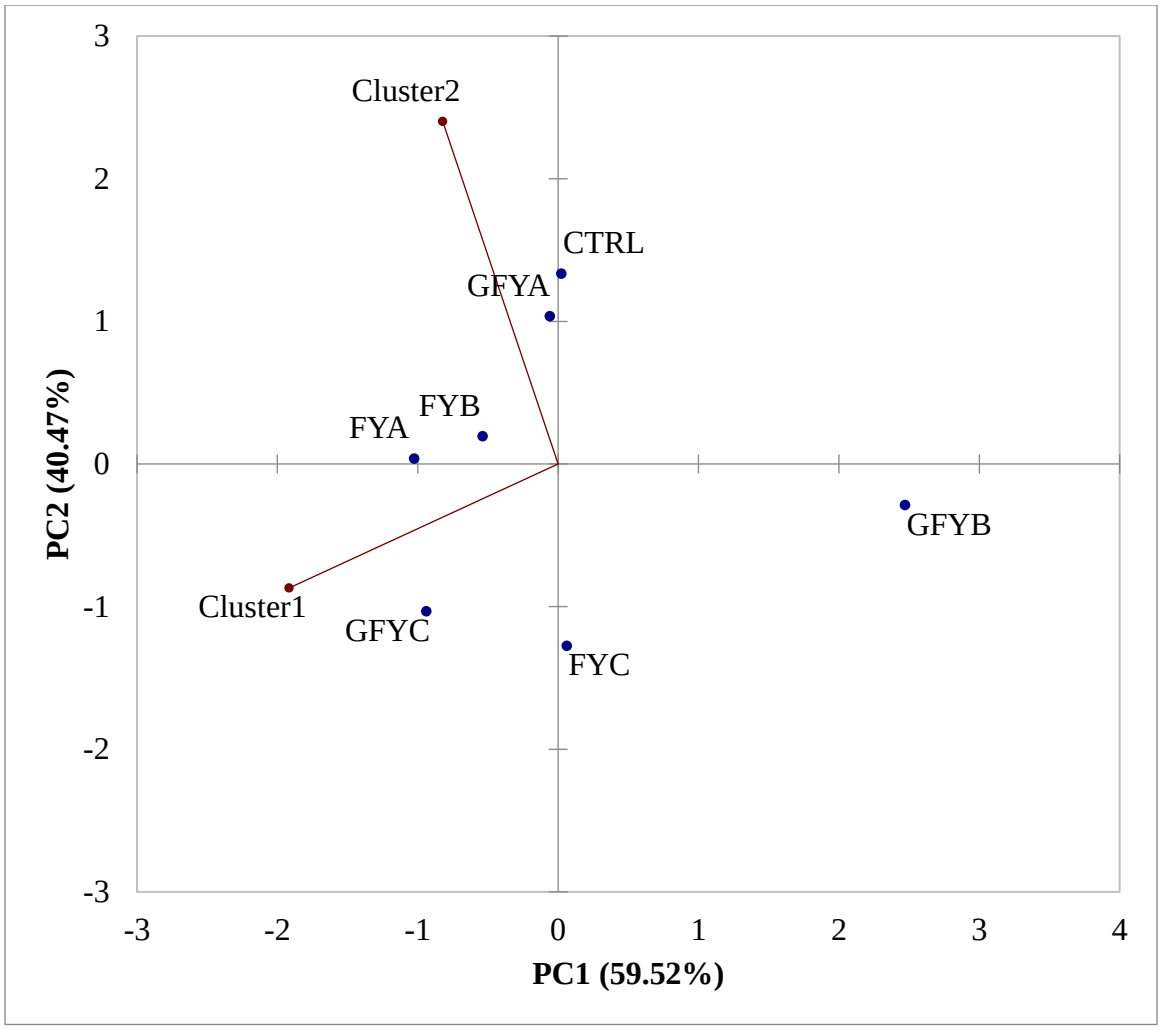


Figure 6-7 External preference mapping of consumer perception of appearance liking of seven frozen desserts using descriptive data and hedonic data

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code:	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
FYB	85% ice cream/ 15% regular yogurt
FYC	80% ice cream/ 20% regular yogurt
GFYA	90% Ice cream/ 10% Greek yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

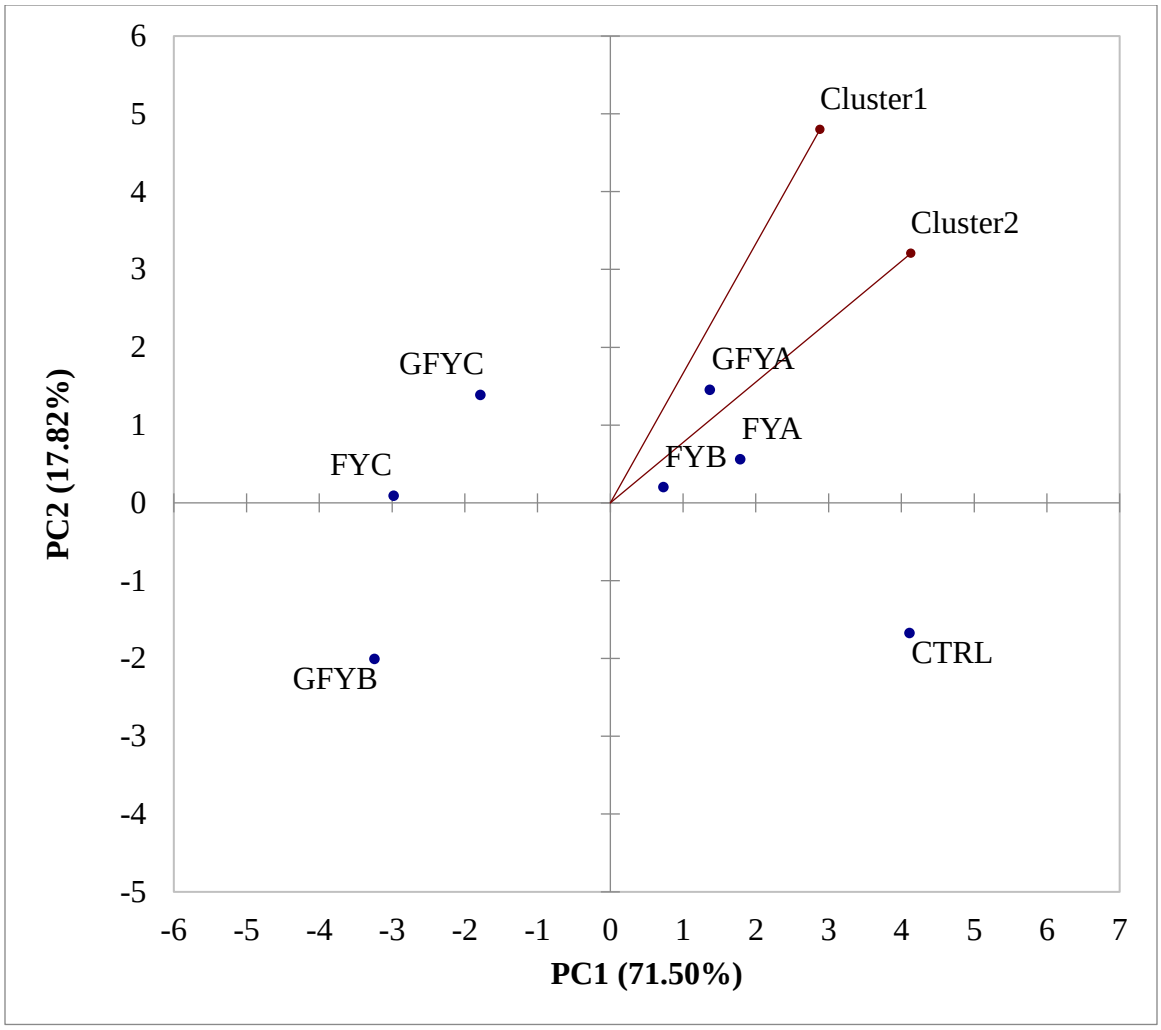


Figure 6-8 External preference mapping of consumer perception of texture liking of seven frozen desserts using descriptive data and hedonic data

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code:	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
FYB	85% ice cream/ 15% regular yogurt
FYC	80% ice cream/ 20% regular yogurt
GFYA	90% Ice cream/ 10% Greek yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

6.4.5 External preference mapping (SensorMineR)

Despite the information gathered from the PREFMAPS developed from the XLSTAT statistical software, they do not provide a clear connection to the preferred frozen dessert treatments among consumers and the attributes of those treatments. Another PREFMAP was developed to understand this relationship by using the SensorMineR R Package. The goal of this map was to attempt to determine which sensory characteristics rated by trained panelists, as described in chapter 5, best explain the differences in overall liking of frozen dessert treatments (Lê and Worch 2018). Unlike the PREFMAPS (XLSTAT) that utilized agglomerative hierarchical clustering to cluster the hedonic ratings by the 101 consumers, each consumer's *overall liking* rating was scaled to produce the PRFEMAP (SensorMineR). The PRFEMAP (SensorMineR) can give more context to the previously developed PREFMAPS (XLSTAT) as the PCA loadings of the PREFMAP are shown simultaneously with contour plot.

PCA analysis was carried out on the mean values of the sensory characteristics (e.g., Sweet Flavor, Hardness, Bitter Flavor, etc.) as described in chapter 5. Another PCA map was generated to show the first two dimensions that explain most of the variation (sum total of 81.4%) from those mean values (Figure 6-9). The relationship between of the complete scaled *overall liking* data, the individual treatments, and the PCA loadings of the sensory variables was shown by combining the PCA model with the full consumer-wise scaled *overall liking* ratings to produce a PRFEMAP (SensorMineR) (Husson and others 2020).

Based on the resulting PREFMAP (Figure 6-10), samples that demonstrate a high intensity of *gooeyness*, *creaminess*, smoothness, gumminess, *mouth coating*, *fat flavor*,

sweet flavor, *milk flavor*, *fat aftertaste*, *sweet aftertaste*, and *milky aftertaste* are more associated with treatments (e.g., Control, FYA, FYB, and GFYA) that were preferred in the consumer sensory analysis – as highlighted by the dark red of the map. Additionally, it is clear that other attributes, such as *bitter flavor*, *alkaline flavor*, *denseness*, and *iciness* are more associated with samples that are not preferred (e.g., FYC, GFYA, and GFYB) – as highlighted by the dark blue of the map. Other attributes, such as the *melting rate*, *alkaline aftertaste*, *bitter aftertaste*, *hardness*, *sour flavor*, *sour aftertaste*, *sheen*, and *fat flavor*, did not contribute significantly to the preference of either type of treatment. However, it is important to note that based on their positioning on the PREFMAP (Figure 6-10), these attributes can be associated with increasing or decreasing a frozen desserts preference among consumers. For example, as *alkaline aftertaste*, *bitter aftertaste*, *hardness*, *sour flavor*, and *sour aftertaste* were found on the far-left side of the PREFMAP in-between to sets of products that were not preferred, these attributes tend to contribute to the disliking of frozen dessert treatments within this study. In contrast, *fat flavor* and *smoothness* were found on the far-right sight of the PREFMAP near treatments that were preferred, indicating that these attributes contribute somewhat to the overall liking of frozen dessert treatments.

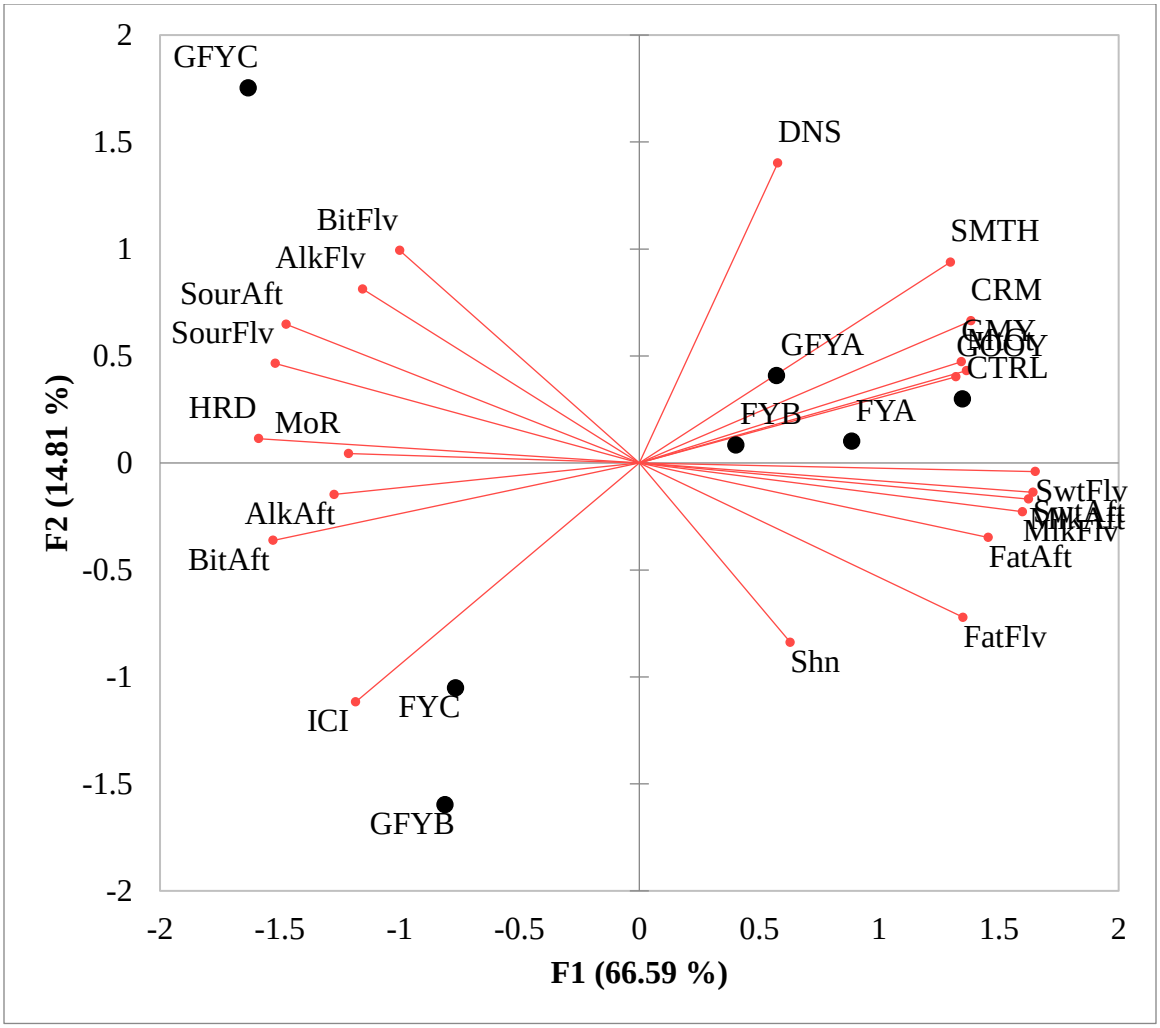


Figure 6-9: PCA Loadings used for Preference Mapping (81.4% of variation in the treatment means of these twenty-two predictors as explained with two dimensions)

Parenthesis denotes the percent explained by the corresponding PC dimensions.	
Product code:	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
FYB	85% ice cream/ 15% regular yogurt
FYC	80% ice cream/ 20% regular yogurt
GFYA	90% Ice cream/ 10% Greek yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

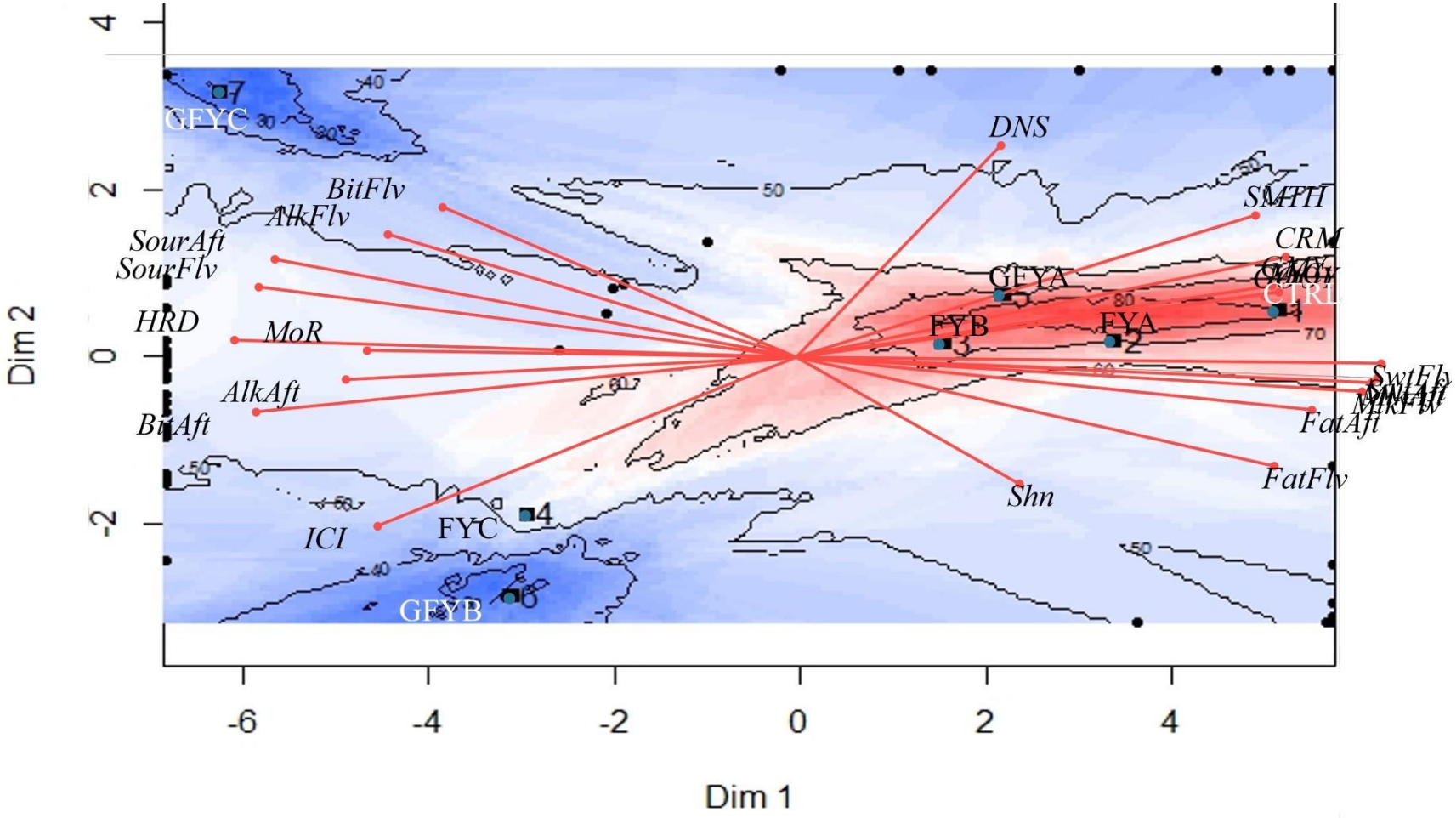


Figure 6-10 Preference map showing loadings of sensory characteristics mapped to liking of specific treatments. dark red means most liked, and dark blue is least liked

6.5 Conclusion

In the present study, it was found that consumers were able to distinguish between provided frozen desserts and that there were significant differences in consumer preference. Among the samples, the control ice cream received the highest hedonic rating of 7.44, and the FYA, FYB and GFYA products were not significantly different from the control. Essentially, products that contain lower concentrations of yogurt were more accepted compared to other products based on their high concentrations of *gooeyness*, *creaminess*, *smoothness, gumminess*, *mouth coating*, *fat flavor*, *sweet flavor*, *milk flavor*, *fat aftertaste, sweet aftertaste,* and *milky aftertaste*. These attributes played an important role in DOL, DOF and DOT of the provided frozen desserts sample. Based on the various external preference maps and Pearson correlation, consumers preferred sweeter treatments over those that contained bitter and sour attributes. O*verall flavor* was most important indicator towards *overall liking* of frozen dessert treatments. *Overall appearance* liking did not contribute much to the *overall liking*. *Overall texture* demonstrated that consumers preferred products that contained either high concentrations of smoothness and creaminess or products that were harder and icier. In general, treatments with lower concentrations of yogurt were accepted by most panelists. However, there was a certain population within this study that preferred the textural attributes of the treatment with the highest concentration of Greek-yogurt – GFYC.

CHAPTER 7

Relationship Between Overall Liking and Physico-Chemical, Organic Acids, Carbohydrates, and Sensory Variables Among Frozen Desserts Containing Various Yogurts

7.1 Introduction

The analysis of data can be a challenging feat regardless of the discipline to assess the relationship between dependent and independent variables. Difficulties arise due to the fact that scholars tend to think within their disciplines (e.g., chemists will utilize chemical methodologies and some statistical analysis). The challenges tend to compound when advanced statistical methodologies are combined with a discipline, as the complexities of the optimal design of an experiment may not be feasible in a discipline. Unique fields, such as chemometrics, attempt to tackle both of these challenges to resolve complex data involving experimental design, pattern recognition, multivariate techniques, and statistical methods (Brereton 2007). This study aims to utilize some of these techniques in the analysis of multiple variables across multiple data sets in relation to the *Overall Liking* variable from the consumer sensory analysis study in Chapter 6.

There are many supervised and unsupervised methods to assess a variety of data sets. In regard to this study, there is a large quantity of variables present to analyze and a succinct method to accurately describe these attributes is needed. Among the supervised methods, the multivariate regression analysis works well at analyzing more than one independent variable in relationship to one dependent variable. This method accounts for the variation of the independent variables with the dependent variable and assumes that

the data is normally distributed, linear, free from extreme values, and having no ties between independent variables (Tabachnik and Fidell 1996; Uyanık and Güler 2013). Unsupervised methods involve exploratory data analysis (EDA) rather than concrete associations among independent and dependent variables. Principal component analysis (PCA) and factor analysis (FA) are the typical methodologies used to assess patterns within a complex data set (Brereton 2007; Rahman and others 2020). Multiple factor analysis (MFA) is a multivariate data analysis method that summarizes and visualizes complex data described by quantitative and/or qualitative variables into structured groups (Bécue-Bertaut and Pagès 2008). This method takes principles from PCA and Multiple correspondence analysis (MCA) and takes the contribution of all active groups of variables to define distance between individuals and groups (Abdi and Williams 2010). MFA has been demonstrated successfully in multiple fields, including ecology, surveys, and sensory analysis (Le Dien and Pagès 2003).

The goal of this study was to discover the best parametric and nonparametric methods to analyze the relationship between the *Overall Liking* variable and other sensory and instrumental data among frozen dessert treatments.

7.2 Materials

The averages of each attribute from the previous studies were pooled into one table to assess the feasibility of various statistical methods on analyzing the relationship between *Overall Liking* of the previously developed frozen yogurts, descriptive data, and non-sensory data (e.g., Physico-chemcial, textural, etc.). Multiple groups of variables were pooled together for the multiple factor analysis (MFA) methodology (Table 7-1). This was done to assess the relationship among the groups of variables instead of each

variable individually, as well as to see which attributes are closely associated with *Overall Liking.*

Table 7-1 Group Categories and their respective variables for multiple factor analysis (MFA) methodology

Physico-Chemical	Physical Instrumental	Organic Acids	Carbohydrates	Descriptive Analysis	Preference Analysis
Overrun	K1	Citric Acid	Sucrose	Sheen	Overall Flavor
TA	n	Pyruvic Acid	Lactose	Gooeyness	Overall Appearance
pH	Particle Size	Lactic Acid	Glucose	HardnessD (Descr. Analysis)	Overall Texture
Melting Rate (Physico)	Hardness (TPA)	Uric Acid	Galactose	Melting Rate (Descriptive)	Overall Liking
Protein	Cohesiveness	Formic Acid		Creaminess	Denseness
Moisture	Springiness	Acetic Acid		Iciness	
Fat	Gumminess (TPA)	Propionic Acid		Smoothness	
Fiber	Chewiness	Butyric Acid		GumminessD (Descr. Analysis)	
Ash	Resilience			Mouth Coating	
Carbohydrate				Sour Flavor	
				Fat Flavor	
				Bitterness Flavor	
				Alkaline Flavor	
				Sweet Flavor	
				Milk Flavor	
				Sour Aftertaste	
				Fat Aftertaste	
				Bitter Aftertaste	
				Alkaline Aftertaste	
				Sweet Aftertaste	
				Milk Aftertaste	

7.3 Data analysis

Principal components analysis (PCA), multiple linear regression, and multiple factor analysis (MFA) was performed on the pooled data set of the means values of 7 frozen desserts for all the variables that were analyzed in the previous chapters. Complete details of each analysis are included in the results and discussion sections below. All analyses were carried out using the R statistical software. All R code that was used as shown in Appendix I.

7.4 Results & discussions

7.4.1 Principal component analysis (PCA)

Principle component analysis (PCA) was used to describe the interrelationships among the multiple dependent variables for all the data from this study of the seven frozen dessert products. The first two principal components (PC) of the PCA accounted for 74.6% of the total variance in the data set (Figure 7-1). The first PC explained 56.1% of the variance and the second PC explained 18.5% of the variance.

PCI was characterized by higher averages and positive values of *overall flavor*, *milk flavor*, *sweet flavor*, *overall liking*, *fat flavor*, and *titratable acidity*. PCI also demonstrated high averages and negative values for *hardness* (*descriptive analysis*), *sour flavor*, *sour aftertaste*, *pH*, *lactic acid*, *particle size*, *protein*. *Glucose* was the only attribute that demonstrated a positive value onto PCII, while *fiber* and *overrun* demonstrated negative values.

These results are similar to those found in Chapter 5, but also demonstrate how attributes from other studies (e.g., Organic Acids, Carbohydrates, Physico-Chemical) correlate with the descriptive and consumer date that were previously generated in

Chapter 5 and 6. As figure 7-1 demonstrates, PCI contributed most of the variance in model (approximately 75%); the treatments can be differentiated by the aforementioned positive and negatively loaded attributes on the first dimension of each model compared to the attributes loaded on PCII (18.5%). Based on this information of this PCA model, attributes such as *overall flavor*, *milk flavor*, *sweet flavor*, *fat flavor*, and *titratable acidity* have a high association to the *Overall Liking* of the treatments in this study. High averages of these flavor attributes and lower titratable acidity values contribute to a higher overall liking. Conversely, attributes such as *hardness* (*descriptive analysis*), *sour flavor*, *sour aftertaste*, *pH*, *lactic acid*, *particle size*, *protein* are negatively associated with the *Overall Liking* variable due to the fact they are negatively strong associations the PC1 of this model.

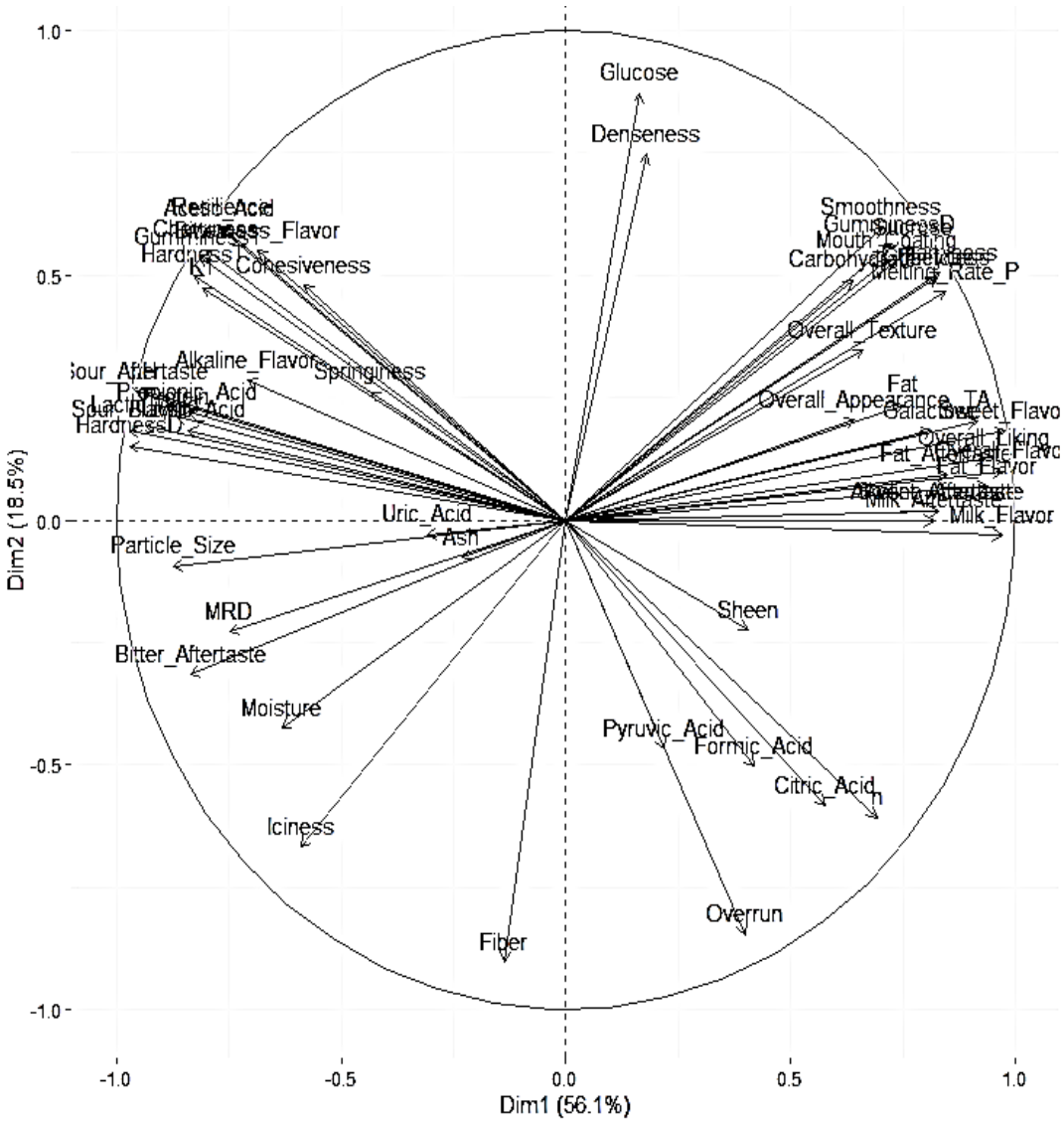


Figure 7-1 Principal component analysis of 57 attributes for seven frozen desserts on PC I and PC II (Correlation-Pearson model)

Parenthesis denotes the percent explained by the corresponding PC dimensions

Attribute Code:

MRD	Melting Rate Descriptive Analysis	Melting_Rate _P	Melting Rate (Physico-Chemcial)

7.4.2 Multiple linear regression

Data was first mean-centered and scaled given that predictors (Table 7-1) and response variable (*Overall Liking*) are on different scales. Next, backward/forward stepwise selection was used to choose the model with the best (smallest) Akaike information criterion (AIC) value starting with the full potential model using the predictors found in Table 7-1. This is done to reduce the number of insignificant terms contributing to the response factor found within the model. The initial equation below was utilized to determine the optimal model for determining *Overall Liking* among the large data set from this study:

$$Overall\ Liking \sim Sweet\_Flavor + Sour\_Aftertaste + \ HardnessD + 54\ predictors$$

An error message was produced with this equation. The model and selection process were redone with the top twenty attributes from the first two dimensions of the generated PCA (Figure 7-1). The following model was then produced for the best prediction of *Overall Liking* amoung the frozen dessert treatments:

$$Overall\ Liking \sim Sweet\_Flavor + Overall\_Flavor + \ Milk\_Flavor$$

Variance inflation factor (VIF) analysis of this model suggested that the model was less than optimal due to extremely high VIF values for each predictor. Despite the lack of optimum functionality, the selected model was fit, and the estimates were

obtained of p-values and coefficients for each factor in the model (Table 7-2). For this model, the adjusted R-squared is 1, suggesting that the predictors describe approximately 100% of the variance in the *Overall Liking* attribute. The p-values for the model and respective predictors of *sweet flavor*, *overall flavor*, and *milk flavor* (P<0.001) indicate that both the model and predictors of this model were highly significant. As this is an investigation of determining the best combination of predictors to predict *Overall Liking*, it was suggested to keep the model at this level, or utilize a simple linear regression to understand the relationship between each predictor and the response individually due to the irregularity of the model. Overall, this model can accurately predict the *Overall Liking* of the frozen dessert treatments from a food science perspective, but it does not accurately reflect the richness of the data set from a statistical perspective.

Table 7-2 Summary of calculated model statistics, including effect estimates

```
Coefficients:
                Estimate Std. Error        t value Pr(>|t|)
(Intercept)     8.497e+02  3.925e-10  2165133985130   <2e-16 ***
Sweet_Flavor    1.084e+01  5.126e-12  2114699341579   <2e-16 ***
Overall_Flavor  1.881e+02  8.636e-11  2177803997618   <2e-16 ***
Milk_Flavor    -2.126e+02  9.830e-11 -2163129670405   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 8.03e-14 on 2 degrees of freedom
Multiple R-squared:      1,     Adjusted R-squared:      1
F-statistic: 1.116e+26 on 3 and 2 DF,  p-value: < 2.2e-16
```

7.4.3 Multiple factor analysis (MFA)

Multiple factor analysis (MFA) was used to describe and visualize the interrelationships among complex multivariate data arising from several sets of variables (quantitative and /or qualitative) structured into groups. This global analysis of the multiple set of variables is balanced and weighted so that the variables in the same group are normalized using the same weighting values. These variables were grouped together based on their respective categories within the study (Table 7-1). MFA is based on other non-parametric analysis such as principal component analysis (PCA) and multiple correspondence analysis (MCA). Similar to PCA, although all loadings are meaningful in each dimension, small loadings mean that the factor is not significant to the dimension of focus (Lawless and Heymann 2010).

Figure 7-2 summarizes the first two dimensions of the MFA, where 73.8% of the total variance in the data set is accounted for. The first dimension explained 53.9% of the variance and the second dimension explained 19.9% of the variance. The first dimension demonstrated a significantly positive correlation ($P<0.001$) with the *overall flavor*, *milk flavor*, *sweet flavor*, *overall liking*, *fat flavor*, and *titratable acidity* variables. It has also demonstrated a significantly negative correlation ($P<0.001$) with *particle size*, *lactic acid*, *pH*, *sour aftertaste*, *sour flavor*, and *hardness (Descriptive Analysis)* variables (Table 7-4). The second dimension demonstrated far fewer attributes, with *glucose* portraying a significantly positive correlation ($p<0.001$) and the *overrun* and *fiber* attributes portraying a significantly negative correlation ($P<0.001$) (Table 7-5). In other words, the MFA results showed that these treatments have great variation among all assigned

variables when various concentrations of yogurt and Greek-yogurt are applied to frozen desserts.

Many variables showed a high affinity to the *Overall Liking* variable in thie MFA model (Figure 7-2). As decribed in Table 7-3, these variables are all located on the far right axis of the MFA model and indicate a positive correlation with the first dimension; Most loadings were positioned in both positive and negative directions along the first dimension. In general, all of the variables in Table 7-2 that have a positive value to their correlation number can be associated with the *Overall liking* variable as they are in close proximity to the far-right position of the first dimension (e.g., the positive side). Attributes such as *overall flavor, milk flavor, sweet flavor, overall liking, fat flavor,* and *titratable acidity* all have positive sentiments to the frozen dessert treatments provided to panelists. In contrast, most of the attributes from the same table, such as *particle size, lactic acid, pH, sour aftertaste, sour flavor,* and *hardness (Descriptive Analysis*), can be associated with why panelists may dislike the provide frozen dessert products. Certain attributes that were found in the middle of the MFA model, such as *uric acid, ash, fiber, sheen, overrun, and pyruvic acid,* may either positively or negatively contribute to the *Overall liking* variable depending on where the variable falls on the plot. However, despite their locations, these attributes do not show a significant correlation with the first two dimensions.

Figure 7-3 visualizes how products that were loaded in the MFA map showed a similar trend to that of the PCAs from the external preference map in chapter 6 (Figure 6-6). In conjunction with the results from that chapter, the products can be attributed to their increase or decrease to a specific variable in the same location of the MFA map.

Products, such as FYA, FYB, and GFYA, were loaded on the right side of the MFA map, similar to the control ice cream product. From the mixed-model ANOVA results and ANOVA results from previous chapters, these products on average showed a high intensity in attributes similar to the control ice cream and show no significant differences. As the control ice cream had significantly higher average value of *overall flavor*, *milk flavor*, *sweet flavor*, *overall liking,* and *fat flavor* attributes then FYA, FYB and GFYA, it was loaded higher on the upper right side of the MFA map in comparison to these products. It could also be said that the control ice cream's lower average value of titratable acidity could contribute to its position as well. The remaining products, FYC, GFYB, and GFYC, were loaded on the left side of the MFA. Based on mixed-model ANOVA results and ANOVA results from previous chapters, these products on average showed a significantly higher average value in *particle size*, *lactic acid, pH, sour aftertaste*, *sour flavor,* and *hardness (Descriptive Analysis*). As a result, these attributes may contribute to the panelists low preference scores for these products.

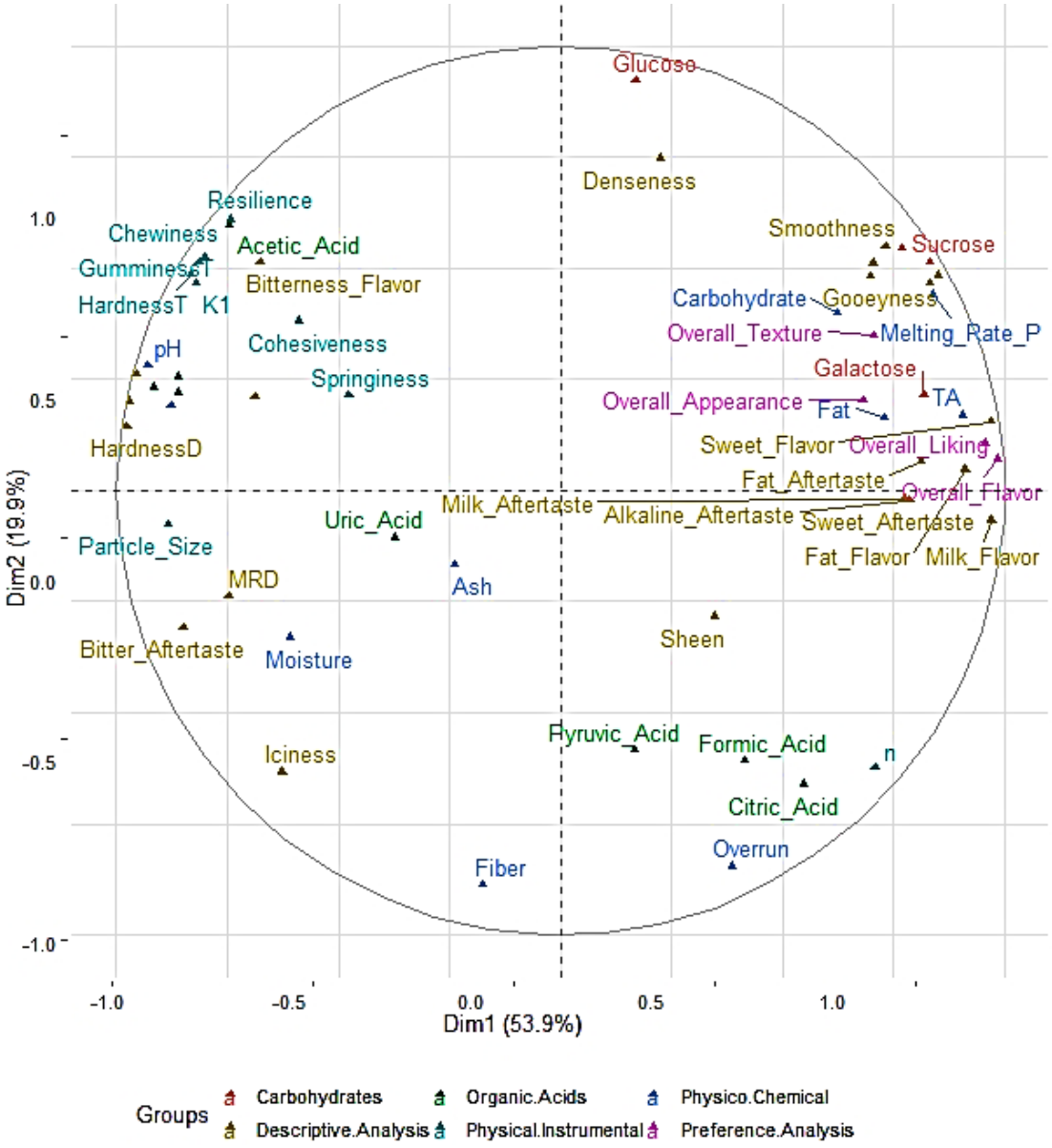


Figure 7-2 Multiple factor analysis (Quantitative Variables) of 6 groups and 57 attributes for seven frozen desserts on Dimensions 1 and 2

Parenthesis denotes the percent explained by the corresponding PC dimensions

Attribute Code:

MRD	Melting Rate Descriptive Analysis	**Melting_Rate _P**	Melting Rate (Physico-Chemcial)
Hardness_T	Hardness (Texture Profile Analysis)	**Gumminess_T**	**Gumminess** (Texture Profile Analysis)
K1	Consistency Index	**n**	Flow Behavior Index
TA	Titratable Acidity		

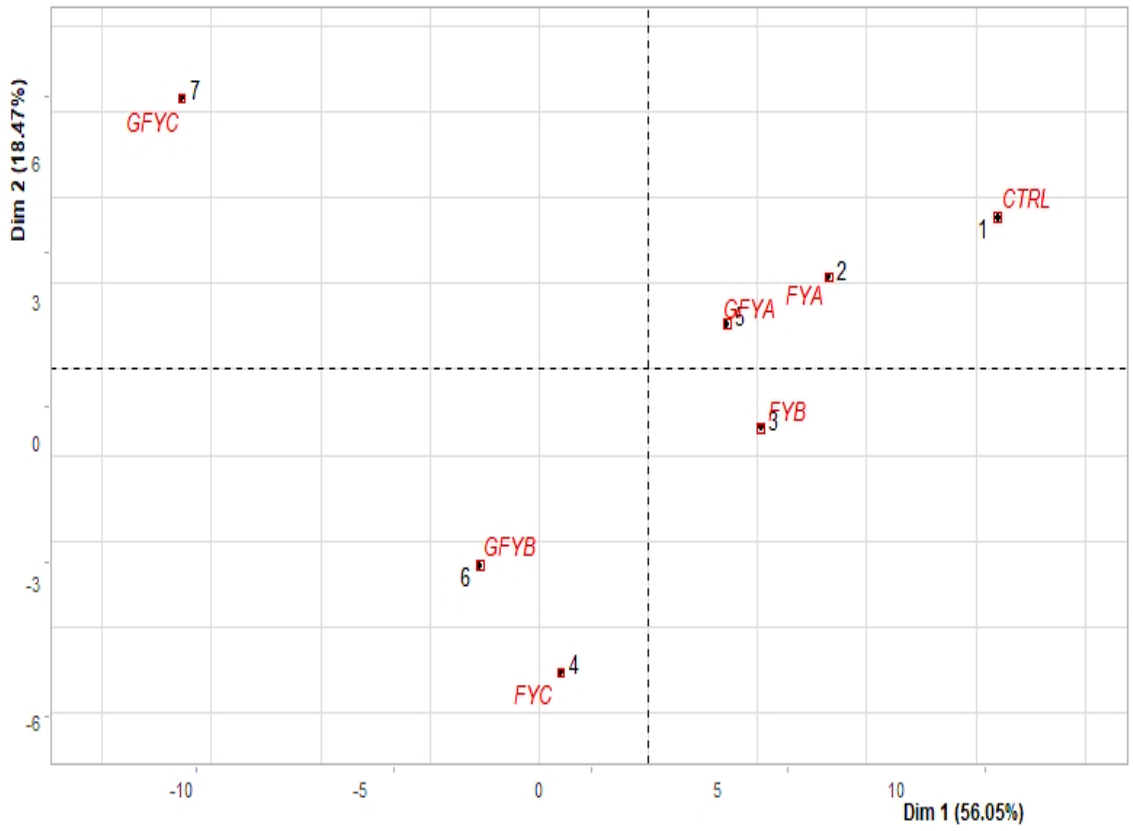


Figure 7-3 Multiple factor analysis (Individual Treatments) of 6 groups and 57 attributes for seven frozen desserts on Dimensions 1 and 2

Parenthesis denotes the percent explained by the corresponding PC dimensions	
Product Code	
CTRL	Control Ice cream (no yogurt added)
FYA	90% Ice cream/ 10% regular yogurt
FYB	85% ice cream/ 15% regular yogurt
FYC	80% ice cream/ 20% regular yogurt
GFYA	90% Ice cream/ 10% Greek yogurt
GFYB	85% ice cream/ 15% Greek yogurt
GFYC	80% ice cream/ 20% Greek yogurt

7.4.3.1 Eigenvalues and dimension description

Based on the results of the eigenvalues from the generated MFA model (Table 7-3), dimensions one and two produced eigenvalues of 4.52 and 1.66 respectively. The main dimension, dimension one, seems to explain a large amount variation (53.94%) among the statistical space of the data set. Combining the first two dimensions, approximately 73.87% of the cumulative data can be explained by the MFA model. In other words, a good portion of the data set can be explained by the first two dimensions among the entire data set. A dimension description was conducted to identify the most significantly associated variables within the first dimension (Table 7-4) and second dimension (Table 7-5).

Table 7-3 Summary of eigenvalues and variation statistics for the MFA model

Dimension	eigenvalue	Variance Percent (%)	Cumulative Variance Percent (%)
Dimension 1	4.5224167	53.947008	53.94701
Dimension 2	1.6698272	19.919036	73.86604
Dimension 3	1.0303478	12.290814	86.15686
Dimension 4	0.5278454	6.296562	92.45342
Dimension 5	0.3711868	4.427814	96.88123
Dimension 6	0.2614484	3.118766	100.00000

Table 7-4 Summary of significant variables, their correlation values, and significance to the first dimension of the MFA model

Attributes with positive correlation	Correlation	P.value	Attributes with negative correlation	Correlation	P.value
Overall Flavor	0.9838	6.34966E-05	Chewiness	-0.8008	0.0304
Milk Flavor	0.9700	2.94E-04	Gumminess (TPA)	-0.8145	0.0256
Sweet Flavor	0.9690	3.18E-04	K1	-0.8220	0.0232
Overall Liking	0.9549	8.07E-04	Hardness (TPA)	-0.8326	0.0201
Fat Flavor	0.9108	4.35E-03	Bitter Aftertaste	-0.8501	0.0153
Titratable Acidity	0.9052	5.04E-03	Butyric Acid	-0.8589	0.0132
Creaminess	0.850	0.0151	Propionic Acid	-0.8605	0.0129
Melting Rate (Physico-Chemical)	0.8374	0.0187	Protein	-0.8776	9.42E-03
Lactose	0.8302	0.0207	Particle Size	-0.8841	8.25E-03
Gooeyness	0.829	0.0208	Lactic Acid	-0.9144	3.93E-03
Galactose	0.8172	0.0247	pH	-0.9295	2.44E-03
Fat Aftertaste	0.8104	0.0270	Sour Aftertaste	-0.9544	8.32E-04
Sweet Aftertaste	0.7849	0.0365	Sour Flavor	-0.9712	2.65E-04
Alkaline Aftertaste	0.7849	0.0365	Hardness (Descriptive Analysis)	-0.9763	1.65E-04

Table 7-5 Summary of significant variables, their correlation values, and significance to the second dimension of the MFA model

Attribute	Correlation	P.value
Glucose	0.9220	3.12E-03
Overrun	-0.8459	0.016446
Fiber	-0.8867	7.80E-03

7.4.3.2 RV coefficients and plot of group variables

The RV coefficient matrix generated the association values between the structured groups within the MFA model. RV coefficients represent a multivariate generalization of the squared Pearson correlation coefficients that measures the proximity of two sets of groups (Robert and Escoufier 1976) between 0 and 1, where 0 equals no relationship between groups and 1 equals an extremely strong relationship between groups (Lê and Worch 2018). The RV coefficients measured between *Descriptive Analysis* and *Carbohydrates* (0.74), *Organic Acids* and *Physical-Instrumental* (0.72), *Descriptive Analysis* and *Preference Analysis* (0.71), and *Descriptive Analysis* and *Physico–Chemical* (0.79) indicated a strong link among these group combinations (Table 7-6). Although there is a strong correlation, these configurations are not homothetic; a portion of the information present in one or two of the combinations of data sets cannot be explained by the other group (Lê and Worch 2018). The RV coefficients measured between the *Carbohydrates* group and *Organic Acids* (0.29), *Preference Analysis* (0.46), and *Physical-Instrumental* (0.25) indicated a weak link among these group combinations. Another set of weak associations were found between *Preference Analysis* group with the *Physical-Instrumental* (0.46) and *Physico–Chemical* (0.48) groups Table 7-6). The *Descriptive Analysis* group demonstrated the highest RV coefficient within the MFA model. However, it is important to note that this group had the largest number of variables compared to the other groups.

Based on the analysis of the contribution of each group of variables towards the first two dimensions (Appendix H), *Descriptive Analysis*, *Physico-Chemcical* and

Preference Analysis demonstrate the highest contribution to the first dimension (above 60%); The *Organic Acids*, *Carbohydrates*, and *Physico-Chemcical* groups demonstrate the highest contribution to the second dimension (above 60%). Despite the lack of significant contributions of some groups, the coordinates locations of the majority of groups are highly congregated near each other in the first dimension at values between 0.70 and 1, indicating that they all have a positive contribution to this dimension with *Descriptive Analysis* demonstrating the highest coordinate (Figure 7-4). Although the *Carbohydrates* and *Physico-Chemcical* contribute the highest contribution to the second dimension, they do not show a strong contribution to dimension one.

7.4.3.3 Partial axis of MFA groups

These associations can also be demonstrated in the partial axes graph that plots the first two dimensions of each group in the MFA model (Figure 7-5). The first dimension of each of the MFA plot demonstrates a high correlation between Descriptive Analysis and Carbohydrates, Organic Acids and Physical-Instrumental, Descriptive Analysis and Preference Analysis, and Descriptive Analysis and Physico–Chemical pairings. The first plane of the plot is the best possible two-dimensional solution to explain the group parings (Lê and Worch 2018).

Table 7-6 RV coefficient matrix of 6 categorical groups for an MFA model assessing frozen desserts with various yogurt types and concentrations (n=7)

	Organic Acids	Carbohydrates	Descriptive Analysis	Preference Analysis	Physical Instrumental	Physico-Chemical	MFA
Organic Acids	1.0000	0.2909	0.6194	0.5613	0.7152	0.5122	0.7801
Carbohydrates	0.2909	1.0000	0.7379	0.4690	0.2512	0.6406	0.7088
Descriptive Analysis	0.6194	0.7379	1.0000	0.7118	0.5278	0.7992	0.9225
Preference Analysis	0.5613	0.4690	0.7118	1.0000	0.4647	0.4859	0.7710
Physical Instrumental	0.7152	0.2512	0.5278	0.4647	1.0000	0.5613	0.7391
Physico-Chemical	0.5122	0.6406	0.7992	0.4859	0.5613	1.0000	0.8424
MFA	0.7801	0.7088	0.9225	0.7710	0.7391	0.8424	1.0000

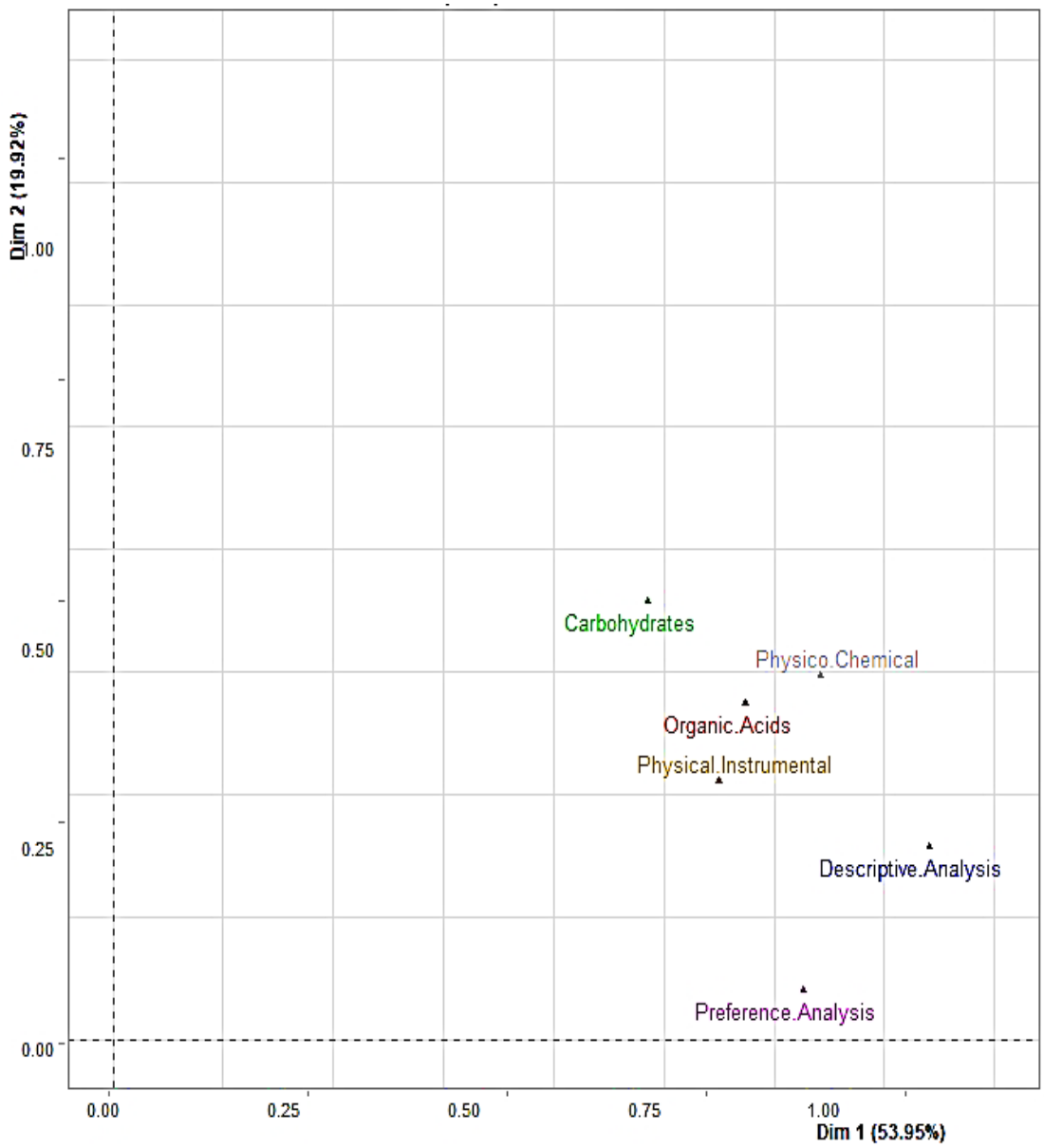


Figure 7-4 Multiple factor analysis (Variable Groups) of 6 groups for seven frozen desserts on Dimensions 1 and 2

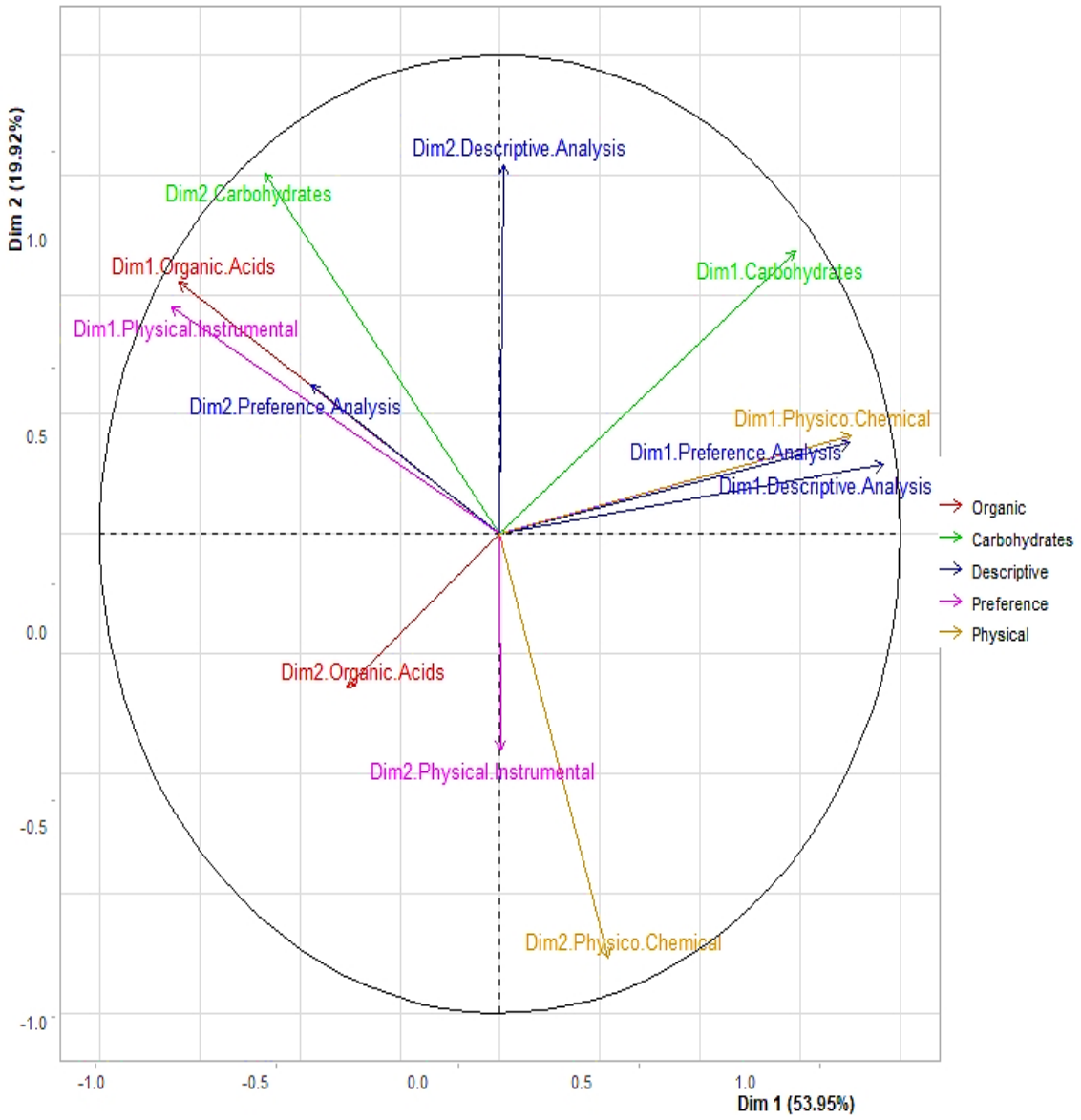


Figure 7-5 Multiple factor analysis (Partial Axes) of 6 groups for seven frozen desserts on Dimensions 1 and 2

7.4.3.4 Dimensionality of variable groups

The dimensionality of each group found within the MFA model was assessed (Table 7-7). This type of analysis involves the dimensionality of each group separately (N_g coefficients) and the common structure between two groups (L_g coefficients). Among the data within the MFA model, *Organic Acids* (N_g = 1.20) and *Physico–Chemical* (N_g = 1.19) appear to be more multidimensional than *Preference Analysis* (N_g = 1.00). Additionally, the L_g coefficients measured between *Organic Acids* and *Physical-Instrumental* (L_g = 0.71), *Organic Acids* and *Descriptive Analysis* (L_g = 0.79), *Physico–Chemical* and *Carbohydrates* (L_g = 0.71), *Descriptive Analysis* and *Preference Analysis* (L_g = 0.74), and *Descriptive Analysis* and *Physico–Chemical* (L_g = 0.91) demonstrate that these groups can be used to explain the attributes found with their respective pairs. However, despite the high interdependence among the pairs, portions of each pair remain particular to their respective groups based on their respective dimensional sizes (Lê and Worch 2018). For example, despite the *Organic Acids* and *Physical-Instrumental* pair demonstrating a higher common structure compared to other pairings (L_g = 0.71), certain aspects of this pairing cannot fully explain the other. A part of the *Organic Acids* group will remain particular to itself when paired with *Physical-Instrumental* as the *Organic Acids* group has a higher dimensionality compared to *Physical-Instrumental* (N_g (*Organic Acids*) = 1.20 versus (N_g (*Physical-Instrumental*) = 1.01).

Table 7-7 Dimensionality matrix of 6 categorical groups for an MFA model assessing frozen desserts with various yogurt types and concentrations (n=7)

	Organic Acids	Carbohydrates	Descriptive Analysis	Preference Analysis	Physical Instrumental	Physico-Chemical	MFA
Organic Acids	1.2043	0.3243	0.7076	0.6188	0.7918	0.6154	0.9424
Carbohydrates	0.3243	1.0320	0.7803	0.4786	0.2575	0.7125	0.7927
Descriptive Analysis	0.7076	0.7803	1.0835	0.7443	0.5543	0.9107	1.0571
Preference Analysis	0.6188	0.4786	0.7443	1.0091	0.4709	0.5343	0.8526
Physical Instrumental	0.7918	0.2575	0.5543	0.4709	1.0177	0.6199	0.8208
Physico-Chemical	0.6154	0.7125	0.9107	0.5343	0.6199	1.1984	1.0152
MFA	0.9424	0.7927	1.0571	0.8526	0.8208	1.0152	1.2119

7.5 Conclusion

The statistical methodologies demonstrated unique ways of assessing the relationship between *Overall Liking* and variables from sensory and non-sensory data collected from frozen desserts developed with different types and concentrations of yogurts. The PCA model described *overall flavor*, *milk flavor*, *sweet flavor*, *overall liking*, *fat flavor*, *titratable acidity*, *hardness* (*Descriptive Analysis*), *sour flavor*, *sour aftertaste*, *pH*, *lactic acid*, *particle size*, and *protein* as the significant attributes to explain differences among the treatments. The multiple linear regression demonstrated that *overall flavor*, *milk flavor*, *sweet flavor* were the most significant variables among all of the data that best predict the *Overall Liking* of treatments, despite the overfit nature of the model.

The MFA model demonstrated a unique perspective in assessing the relationship between the *Overall Liking* among the frozen dessert treatments and the other 57 variables in the dataset. The MFA model found associations among *Overall Liking* and its categorical group, *Preference Analysis*, in comparison to other variables and categories representing sensory and non-sensory data. The results indicated that there are relationships among the variables in different sensory and non-sensory categories. This statistical analysis provides evidence that the *Overall Liking* of frozen dessert treatments within this study can be assessed from both a sensory and non-sensory perspective in the same model. It provides a unique, flexible, and detailed perspective in comparison to the parametric multiple linear regression and non-parametric principal component analysis.

CHAPTER 8

Conclusions

This dissertation focused on designing formulas of frozen desserts with various concentrations and types of yogurts to provide consumers with a product that meets some of their major nutritional needs. Across the majority of this project, treatments with lower concentrations of yogurt were significantly similar to the control ice cream – including the frozen dessert with Greek yogurt at its lowest concentration (10%). Many analyses have indicated that certain variables tend to increase at exponential levels with treatments containing higher formulations of yogurt – regardless of the yogurt type. Treatments with formulations of 15% and 20% Greek yogurt have been shown to increase attributes that contribute a negative response in a consumer study, including acidity, viscosity, hardness, iciness, bitterness, and sourness. Although previous chapters have summarized their respective niches, we summarize the most important conclusions from each section to provide a wholistic perspective of this project.

The various attributes of frozen desserts, such as overrun, melting rate, pH, titratable acidity, proximate analysis, texture profile analysis, particle size and rheological properties, were investigated among frozen desserts containing set yogurt and Greek-style yogurt. Our results clearly indicated that despite the lack of significant differences among macronutrients, significant differences could be observed among pH, titratable acidity, hardness, gumminess, chewiness, particle size and flow behavior at small changes in the frozen dessert formulation. Treatments containing higher yogurt

concentrations, especially those with Greek yogurt, demonstrated the highest significance among the aforementioned attributes.

The chemical compounds used to develop various standard curves functioned well for method validation and overall analysis of organic acid and carbohydrate in frozen dessert treatments. The precision study suggests that extraction of all compounds was repeatable, with all compounds falling below 5% RSD, an acceptable level for analysis. The recovery study demonstrated the efficiency of this method regardless of the various food matrix that was utilized. Based on the results of these studies, citric acid, formic acid, sucrose, lactose, and glucose demonstrated a decrease in their average concentration as more of any yogurt type was applied to the control ice cream; on the other hand, the concentration of lactic acid, acetic acid, propionic acid, and butyric acid increased in concentration as more of any yogurt type was applied to the control ice cream.

The descriptive analysis conducted in this study showed that more than half of the flavor and texture attributes developed had significant differences across the tested products. The control ice cream and the frozen dessert with Greek yogurt at its lowest concentration (20%) held the highest intensity for most of the attributes with high significant differences. PCA indicated that the control ice cream had a high intensity in sheen, gooeyness, creaminess, denseness, smoothness, gumminess, mouth coating, fat flavor, sweet flavor, milk flavor, fat aftertaste, sweet aftertaste, and milk aftertaste. The cluster analysis demonstrated that the intensity of sweet flavor, fat flavor, milky flavor, sour flavor, hardness, and iciness attributes was a determinant in dissimilarity of taste among the tested products.

It was found that consumers were able to distinguish between provided frozen desserts and that there were significant differences in consumer preference. Among the samples, the control ice cream received the highest hedonic rating of 7.44, and the treatments with lower concentrations of yogurt and Greek-yogurt were not significantly different from the control. Essentially, products that contain lower concentrations of yogurt were more accepted compared to other products based on their high volumes for *gooeyness, creaminess, smoothness, gumminess, mouth coating, fat flavor, sweet flavor, milk flavor, fat aftertaste*, *sweet aftertaste,* and *milky aftertaste*. These attributes played an important role in measurements of degree of overall liking, flavor, appearance, and texture of the provided frozen desserts samples. Based on the various external preference maps and Pearson correlation, consumers preferred sweeter treatments over those that contained bitter and sour attributes. *Overall flavor* was the most important indicator towards *overall liking* of frozen dessert treatments. *Overall appearance* liking did not contribute much to the *overall liking*. *Overall texture* demonstrated that consumers preferred products that contained either high concentrations of smoothness and creaminess or products that were harder and icier. In general, Greek yogurt as an ingredient within frozen desserts was accepted by panelists when a low concentration was utilized.

The statistical methodologies demonstrated unique ways of assessing the relationship between *Overall Liking* and variables from sensory and non-sensory data collected from frozen desserts developed with different types and concentrations of yogurts. The PCA model described *overall flavor*, *milk flavor*, *sweet flavor*, *overall*

liking, *fat flavor*, *titratable acidity*, *hardness* (*Descriptive Analysis*), *sour flavor*, *sour aftertaste*, *pH*, *lactic acid*, *particle size*, and *protein* as the significant attributes to explain differences among the treatments. The multiple linear regression demonstrated that *overall flavor*, *milk flavor*, *sweet flavor* were the most significant variables among all of the data that best predict the *Overall Liking* of treatments, despite the overfit nature of the model.

The MFA model demonstrated a unique perspective in assessing the relationship between the *Overall Liking* among the frozen dessert treatments and the other 57 variables in the dataset. The MFA model found associations among *Overall Liking* and its categorical group, *Preference Analysis*, in comparison to other variables and categories representing sensory and non-sensory data. The results indicated that there are relationships among the variables in different sensory and non-sensory categories. This statistical analysis provides evidence that the *Overall Liking* of frozen dessert treatments within this study can be assessed from both a sensory and non-sensory perspective in the same model. It provides a unique, flexible, and detailed perspective in comparison to the parametric multiple linear regression and non-parametric principal component analysis.

Overall, the addition of Greek-yogurt as a functional ingredient within a frozen dessert system appears to be an acceptable product by consumers at concentrations at or below 10%. Across the various studies in this dissertation, it was found that there were no or minimal statistical difference between the control ice cream and frozen desserts that contained low concentrations of yogurt (e.g., frozen yogurt with 10-15% yogurt and frozen yogurt with 10% Greek-yogurt). However, when larger concentrations of yogurt are applied to frozen desserts, various sensory and non-sensory attributes tend to increase

or decrease in the food matrix, decreasing consumer acceptance of those treatments. It is suggested future research should focus on ingredients that improve consumer acceptance of the frozen dessert product as higher concentrations of it are utilized.

Chapter 9

Future research directions

There are a multitude of ways to extend this project to discover new insights regarding functional ingredients within frozen desserts. From a microbial perspective, a study can be conducted to determine the viability of different probiotics within frozen desserts; this would demonstrate the effects of Greek yogurt on viability of the probiotic *L. acidophilus* compared to other common frozen desserts. This could be done in tandem with a shelf-life study and should be extended to 3 to 6 months. The colony count of *L. acidophilus* can be enumerated in each frozen dessert sample using de Man, Rogosa, and Sharpe (MRS)-sorbitol and MRS-NNLP (where NNLP = nalidixic acid, neomycin sulfate, lithium chloride, and paromomycin sulfate) agar plates, respectively (Akalın and others 2018). One could take the study a step further by applying more probiotics, such as *B. lactis* and *B. longum,* to all treatments to determine their viability rates at the same time.

The potential of Greek yogurt as a stabilizer within frozen dessert samples can be explored by comparing different concentrations of yogurt and stabilizers within frozen desserts. The application of set yogurt to ice cream creates a colloidal system that essential slightly disrupts the emulsion due to the lowered pH presence, but also assists in stabilization of air-serum and fat-serum interfaces with the extra proteins. Since the whey protein-casein ratio of Greek yogurt is different compared to set yogurt (with a higher concentration of casein due to the strained acid whey), it is expected that the increased concentration of casein will help further stabilize the foam colloidal system. Work from

Zhang and Goff (2004) and Goff and others (1999) demonstrate that non-micellar caseins tend to adsorb at both fat–serum and air–serum interfaces. Zhang and Goff (2004) discovered that the partial dissociation of casein micelles in solution led them to migrate and adsorb to air/water interfaces, but there was preferential adsorption of β-casein over other caseins, and caseins over whey proteins. This study should be approached from an optimal condition's perspective (Response surface methodology) rather than a completely randomized design with a one-way ANOVA. One would have to create their own mix and replace a standard stabilizer/emulsifier ingredient with the Greek yogurt product.

From a sensory perspective, the consumer study could be further extended by including an adolescent population in comparison to the typical university population. This would expand the project to show the palettes and perspectives of panelists and demonstrate their preferences by demographic (e.g., age, gender, etc.). Another aspect would be to analyze the consumer data with newer statistical models, such as pivot profile mapping and projective mapping, compared to the classical preference mapping to understand consumer perceptions (Esmerino and others 2017).

Finally, rather than focusing on the non-volatile analytes with each product, one can study the composition of volatile compounds from yogurt, Greek yogurt, and various frozen desserts utilizing adsorption techniques such as solid-phase microextraction (SPME). The goal would be to utilize a gas chromatography instrument with a mass spectrometric detector to compare the loss of flavor notes from the original yogurt products to the frozen dessert samples. This data could be combined with our non-volatile

data to create a larger description of how yogurt and Greek yogurt products change the overall flavor profile of frozen desserts.

Chapter 10

References

Abbasi S, Saeedabadian A. 2015. Influences of lactose hydrolysis of milk and sugar reduction on some physical properties of ice cream. Journal of Food Science and Technology 52(1):367-74.

Abd El-Rahman AM, Madkor SA, Ibrahim FS, Kilara A. 1997. Physical Characteristics of Frozen Desserts Made with Cream, Anhydrous Milk Fat, or Milk Fat Fractions. Journal of Dairy Science 80(9):1926-35.

Abdi H, Williams LJ. 2010. Principal component analysis. Wiley Interdisciplinary Reviews: Computational Statistics 2(4):433-59.

Adhikari K, Grün IU, Mustapha A, Fernando LN. 2002. Changes in the profile of organic acids in plain set and stirred yogurts during manufacture and refrigerated storage. Journal of Food Quality 25(5):435-51.

Adleman R, Hartel RW, Garti G, Sato K. 2001. Crystallization Processes in Fats and Lipid Systems. Boca Raton, FL: Taylor & Francis.

Ahadzi P. 2019. Determination of a Suitable Sensory Protocol (s) to Characterize Frozen Dairy-Based Products. Accra, Ghana: University Of Ghana.

Akalın A, Erişir D. 2008. Effects of inulin and oligofructose on the rheological characteristics and probiotic culture survival in low‐fat probiotic ice cream. Journal of Food Science 73(4):184-8.

Akalın AS, Karagözlü C, Ünal G. 2008. Rheological properties of reduced-fat and low-fat ice cream containing whey protein isolate and inulin. European Food Research and Technology 227(3):889-95.

Akalın AS, Kesenkas H, Dinkci N, Unal G, Ozer E, Kınık O. 2018. Enrichment of probiotic ice cream with different dietary fibers: Structural characteristics and culture viability. Journal of Dairy Science 101(1):37-46.

Alfaifi M, Stathopoulos C. 2010. Effect of egg yolk substitution by sweet whey protein concentrate (WPC), on physical properties of Gelato ice cream. International Food Research Journal 17(3):787-93.

Alfaro L, Hayes D, Boeneke C, Xu Z, Bankston D, Bechtel PJ, Sathivel S. 2015. Physical properties of a frozen yogurt fortified with a nano-emulsion containing purple rice bran oil. LWT-Food Science and Technology 62(2):1184-91.

Alizadeh M, Azizi-Lalabadi M, Kheirouri S. 2014. Impact of using stevia on physicochemical, sensory, rheology and glycemic index of soft ice cream. Food and Nutrition Sciences 2014.

Alvarez VB, Wolters CL, Vodovotz Y, Ji T. 2005. Physical Properties of Ice Cream Containing Milk Protein Concentrates. Journal of Dairy Science 88(3):862-71.

Amaral CRS, Siqueira PB, Yoshiara LY, Nascimento E, de Faria R, Picanço NFM. 2020. Quantitative descriptive analysis and acceptance testing of yogurt with no added sugar. Journal of Food Research 9(2):7-19.

AOAC Official Method 934.01. 2006. Official Methods of Analysis of AOAC INTERNATIONAL, 18 ed. Gaithersburg, MD: AOAC INTERNATIONAL.

AOAC Official Method 942.05. 2006. Official Methods of Analysis of AOAC INTERNATIONAL, 18 ed. Gaithersburg, MD: AOAC INTERNATIONAL.

AOAC Official Method 978.10. 2006. Official Methods of Analysis of AOAC INTERNATIONAL, 18 ed. Gaithersburg, MD: AOAC INTERNATIONAL.

AOAC Official Method 984.13 (A-D). 2006. Official Methods of Analysis of AOAC INTERNATIONAL, 18 ed. Gaithersburg, MD: AOAC INTERNATIONAL.

Araujo P. 2009. Key aspects of analytical method validation and linearity evaluation. Journal of Chromatography B 877(23):2224-34.

Arbuckle WS. 1986. Ice Cream, 4 ed. Westport, Ct: The AVI Publishing Company.

Atamian S, Olabi A, Baghdadi OK, Toufeili I. 2014. The characterization of the physicochemical and sensory properties of full‐fat, reduced‐fat and low‐fat bovine, caprine, and ovine Greek yogurt (Labneh). Food Science and Nutrition 2(2):164-73.

Bahramparvar M, Mazaheri Tehrani M. 2011. Application and Functions of Stabilizers in Ice Cream. Food Reviews International 27(4):389-407.

Baier S, Elmore D, Guthrie B, Lindgren T, Smith S, Steinbach A, Debon S, Vanhemelrijck J, Heyer P, Läuger J. 2009. A new tribology device for assessing mouthfeel attributes of foods. 5th international symposium on food structure and rheology: ETH Zurich Switzerland. p. 432-5.

Barkeling B, Rössner S, Björvell H. 1990. Effects of a high-protein meal (meat) and a high-carbohydrate meal (vegetarian) on satiety measured by automated computerized monitoring of subsequent food intake, motivation to eat and food preferences. International Journal of Obesity 14(9):743-51.

Başyiğit G, Kuleaşan H, Karahan AG. 2006. Viability of human-derived probiotic lactobacilli in ice cream produced with sucrose and aspartame. Journal of Industrial Microbiology and Biotechnology 33(9):796-800.

Bécue-Bertaut M, Pagès J. 2008. Multiple factor analysis and clustering of a mixture of quantitative, categorical and frequency data. Computational Statistics & Data Analysis 52(6):3255-68.

Beecher GR. 1999. Phytonutrients' role in metabolism: effects on resistance to degenerative processes. Nutrition Reviews 57(9):3-6.

Bevilacqua A, Califano A. 1989. Determination of organic acids in dairy products by high performance liquid chromatography. Journal of Food Science 54(4):1076-.

Bigliardi B, Galati F. 2013. Innovation trends in the food industry: the case of functional foods. Trends in Food Science & Technology 31(2):118-29.

Biguzzi C, Schlich P, Lange C. 2014. The impact of sugar and fat reduction on perception and liking of biscuits. Food Quality and Preference 35:41-7.

Borgognone MaG, Bussi J, Hough G. 2001. Principal component analysis in sensory analysis: covariance or correlation matrix? Food Quality and Preference 12(5-7):323-6.

Brereton RG. 2007. Applied chemometrics for scientists. New York, NY: John Wiley & Sons.

Bridge A, Brown J, Snider H, Nasato M, Ward WE, Roy BD, Josse AR. 2019. Greek yogurt and 12 weeks of exercise training on strength, muscle thickness and body composition in lean, untrained, university-aged males. Frontiers in Nutrition 6:55.

Brown-Riggs C. 2016. Nutrition and Health Disparities: The Role of Dairy in Improving Minority Health Outcomes. International Journal of Environmental Research and Public Health 13(1):28.

Brown AC, Shovic A, Ibrahim S, Holck P, Huang A. 2005. A non-dairy probiotic's (poi) influence on changing the gastrointestinal tract's microflora environment. Alternative Therapies in Health and Medicine 11(1):58.

Buriti FC, Komatsu TR, Saad SM. 2007. Activity of passion fruit (Passiflora edulis) and guava (Psidium guajava) pulps on Lactobacillus acidophilus in refrigerated mousses. Brazilian Journal of Microbiology 38(2):315-7.

Bylund G. 2003. Dairy processing handbook: Tetra Pak Processing Systems AB.

Cavitt L, Youm G, Meullenet J, Owens C, Xiong R. 2004. Prediction of poultry meat tenderness using razor blade shear, Allo‐Kramer shear, and sarcomere length. Journal of Food Science 69(1):SNQ11-SNQ5.

CDC. 2015. Strategies to Prevent Obesity. Centers for Disease Control and Prevention; 2015 [Accessed 2019 2/19/2019] Available from: https://www.cdc.gov/obesity/strategies/index.html.

Chan CC, Lee Y, Lam H, Zhang X-M. 2004. Analytical method validation and instrument performance verification. Hoboken, NJ: John Wiley & Sons.

Charalampopoulos D, Pandiella S, Webb C. 2003. Evaluation of the effect of malt, wheat and barley extracts on the viability of potentially probiotic lactic acid bacteria under acidic conditions. International Journal of Food Microbiology 82(2):133-41.

Chramostova J, Mošnová R, Lisova I, Pešek E, Drbohlav J, Němečková I. 2014. Influence of cultivation conditions on the growth of Lactobacillus acidophilus, Bifidobacterium sp., and Streptococcus thermophiles, and on the production of organic acids in fermented milks. Czech Journal of Food Sciences 32(5):422-9.

Cifelli CJ AN, Fulgoni VL 3rd. 2015. Protein in the U.S. Diet and the Contribution of Dairy Foods, Data Brief No. 1502. In: Council ND, editor. Rosemont, IL.

Clarke C. 2015. The Science of Ice Cream. CAmbridge, UK: Royal Society of Chemistry.

Clemente A, Arques MC, Dalmais M, Le Signor C, Chinoy C, Olias R, Rayner T, Isaac PG, Lawson DM, Bendahmane A. 2015. Eliminating anti-nutritional plant food proteins: the case of seed protease inhibitors in pea. PLOS One 10(8).

Clifton P. 2012. Effects of a high protein diet on body weight and comorbidities associated with obesity. British Journal of Nutrition 108(S2):S122-S9.

Clydesdale F. 2004. Functional foods: opportunities & challenges. Food Technology (Chicago) 58(12):35-40.

Costa FF, Resende JV, Abreu LR, Goff HD. 2008. Effect of Calcium Chloride Addition on Ice Cream Structure and Quality. Journal Dairy of Science 91:2165.

Costa M, Balthazar C, Moreira R, Cruz A, Júnior CC. 2013. Leite fermentado: potencial alimento funcional. Enciclopédia Biosfera 9(16).

Costa MPd, Frasao BdS, Lima BRCdC, Rodrigues BL, Junior CAC. 2016. Simultaneous analysis of carbohydrates and organic acids by HPLC-DAD-RI for monitoring goat's milk yogurts fermentation. Talanta 152:162-70.

Cruz AG, Antunes AE, Sousa ALO, Faria JA, Saad SM. 2009. Ice-cream as a probiotic food carrier. Food Research International 42(9):1233-9.

Dalgleish DG. 1990. Denaturation and Aggregation of Serum Proteins and Casiens in Heated Milk. Journal of Agriculture and Food Chemistry 38:1995.

das Graças Pereira G, de Resende JV, de Abreu LR, de Oliveira Giarola TM, Perrone IT. 2011. Influence of the partial substitution of skim milk powder for soy extract on ice cream structure and quality. European Food Research and Technology 232(6):1093-102.

Daw E, Hartel R. 2015. Fat destabilization and melt-down of ice creams with increased protein content. International Dairy Journal 43:33-41.

De Felice S. 2002. FIM. 2002 Available from: https://fimdefelice.org/fim-rationale-and-proposed-guidelines-for-the-nutraceutical-research-education-act-nrea/.

De Simone C, Salvadori BB, Negri R, Ferrazzi M, Baldinelli L, Vesely R. 1986. The adjuvant effect of yogurt on production of gamma-interferon by Con A-stimulated human peripheral blood lymphocytes. Nutrition Reports International (USA).

De Vrese M, Schrezenmeir. 2008. Probiotics, prebiotics, and synbiotics. Food biotechnology: Springer. p. 1-66.

Dixon RA, Steele CL. 1999. Flavonoids and isoflavonoids–a gold mine for metabolic engineering. Trends in Plant Science 4(10):394-400.

Domínguez Díaz L, Fernández-Ruiz V, Cámara M. 2020. An international regulatory review of food health-related claims in functional food products labeling. Journal of Functional Foods 68:103896.

Douglas SM, Ortinau LC, Hoertel HA, Leidy HJ. 2013. Low, moderate, or high protein yogurt snacks on appetite control and subsequent eating in healthy women. Appetite 60:117-22.

Drewnowski A. 2018. Measures and metrics of sustainable diets with a focus on milk, yogurt, and dairy products. Nutrition Reviews 76(1):21-8.

Duttaroy AK. 2019. Regulation of functional foods in European Union: assessment of health claim by the European Food Safety Authority. Nutraceutical and functional food regulations in the United States and around the world: Elsevier. p. 267-76.

E X, Pei ZJ, Schmidt KA. 2010. Ice Cream: Foam Formation and Stabilization—A Review. Food Reviews International 26(2):122-37.

El-Neshawy A, Baky AA, Rabie A, Metwally SA. 1988. Organoleptic and physical properties of ice cream made from hydrolysed lactose reconstituted milk. Food Chemistry 27(2):83-93.

El-Zeini HM, El-Abd M, Metwaly FA, Zeidan M, Hassan Y. 2016. Using Whey Protein Isolate as a Substitute Of Milk Solid Not Fat on Chemical and Physico-Chemical Properties of Ice Cream. Journal of Food and Dairy Sciences 7(2):133-7.

El‐Nagar G, Clowes G, Tudorică CM, Kuri V, Brennan CS. 2002. Rheological quality and stability of yog‐ice cream with added inulin. International Journal of Dairy Technology 55(2):89-93.

El Sohaimy S. 2012. Functional foods and nutraceuticals-modern approach to food science. World Applied Sciences Journal 20(5):691-708.

Esmerino EA, Tavares Filho ER, Carr BT, Ferraz JP, Silva HL, Pinto LP, Freitas MQ, Cruz AG, Bolini HM. 2017. Consumer-based product characterization using Pivot Profile, Projective Mapping and Check-all-that-apply (CATA): A comparative case with Greek yogurt samples. Food Research International 99:375-84.

FAO Food And Nutrition Paper 77. 2003. Food energy - methods of analysis and conversion factors. Rome, Italy: Food And Agriculture Organization Of The United Nations; 2003 Available from: http://www.fao.org/3/Y5022E/y5022e00.htm#Contents.

Favaro-Trindade C, de Carvalho Balieiro J, Dias PF, Amaral Sanino F, Boschini C. 2007. Effects of culture, pH and fat concentration on melting rate and sensory characteristics of probiotic fermented yellow mombin (Spondias mombin L) ice creams. Food Science and Technology International 13(4):285-91.

FDA U. 2011. Food & Drug Administration. Code of Federal Regulations (CFR). April 1st, 2011 ed. Washington, D.C.: GMP Publications. p. 31-9.

Fiat A-M, Migliore-Samour D, Jolles P, Drouet L, Sollier CBD, Caen J. 1993. Biologically active peptides from milk proteins with emphasis on two examples concerning antithrombotic and immunomodulating activities. Journal of Dairy Science 76(1):301-10.

Folch J, Lees N, Sloane Stanley C. 1957. A simple method for the isolation and purification of total lipides from animal tissues. Journal of Biological Chemistry 226(1):497-509.

Frank J. 2014. The Effect of Dietary Fiber on Physio-Chemical and Sensorial Properties of Frozen Yogurt. [Thesis]. Columbia, MO: University of Missouri - Columbia.

Fuller R. 1989. Probiotics in man and animals. Journal of Applied Microbiology 66:131-9.

Gaonkar AG, McPherson A. 2016. Ingredient interactions: effects on food quality. New York, New York: CRC press.

Geilman WG, Schmidt DE. 1992. Physical characteristics of frozen desserts made from ultrafiltered milk and various carbohydrates. Journal of dairy science 75(10):2670-5.

Goff HD, Hartel RW. 2013. Ice cream. New York, NY: Springer Science & Business Media.

Goff HD, Kinsella JE, Jordan WK. 1989. Influence of Various Milk Protein Isolates on Ice Cream Emulsion Stability. Journal of Dairy Science 72(2):385-97.

Goff HD, Verespej E, Smith AK. 1999. A Study of Fat and Air Structures in Ice Cream. International Dairy Journal 9:817.

González de Llano D, Rodriguez A, Cuesta P. 1996. Effect of lactic starter cultures on the organic acid composition of milk and cheese during ripening—analysis by HPLC. Journal of Applied Bacteriology 80(5):570-276.

Góral M, Kozłowicz K, Pankiewicz U, Góral D, Kluza F, Wójtowicz A. 2018. Impact of stabilizers on the freezing process, and physicochemical and organoleptic properties of coconut milk-based ice cream. LWT - Food Science and Technology 92:516-22.

Grand View Research. 2019. Frozen Dessert Market Size, Share & Trends Analysis Report By Distribution Channel, By Product (Confectionaries & Candies, Ice Cream, Frozen Yogurt), By Region, And Segment Forecasts, 2019 - 2025. Grand View Research; 2019 Available from: https://www.grandviewresearch.com/industry-analysis/frozen-dessert-market#:~:text=The%20global%20frozen%20dessert%20market%20size%20was%20estimated%20at%20USD,USD%20106.75%20billion%20in%202020.&text=The%20global%20frozen%20dessert%20market%20is%20expected%20to%20grow%20at,USD%20135.00%20billion%20by%202025.

Grand View Research. 2021. U.S. Frozen Desserts Market Size, Share & Trends Analysis Report By Product (Ice Cream & Gelato, Water & Fruit Puree Based Frozen Desserts), By Type, By Distribution Channel, And Segment Forecasts, 2021 - 2028. Grand View Research; 2021 Available from: https://www.grandviewresearch.com/industry-analysis/us-frozen-desserts-market.

Green JM. 1996. Peer reviewed: a practical guide to analytical method validation. Analytical Chemistry 68(9):305A-9A.

Greenhoff K, MacFie H. 1994. Measurement of food preferences: Preference mapping in practice. Boston, MA: Springer. p. 137-66.

Guarner FS, GJ. 1998. Probiotics. Interational journal of Food Microbiology 39(3):237-8.

Guideline IHT. 2005. Validation of analytical procedures: text and methodology Q2 (R1). International Conference on Harmonization, Geneva, Switzerland. p. 11-2.

Guinard J-X, Mazzucchelli R. 1996. The sensory perception of texture and mouthfeel. Trends in Food Science & Technology 7(7):213-9.

Guinard JX, Little C, Marty C, Palchak TR. 1994. Effect of Sugar and Acid on the Acceptability of Frozen Yogurt to a Student Population. Journal of Dairy Science 77(5):1232-8.

Guner A, Ardıc M, Keles A, Dogruer Y. 2007. Production of yogurt ice cream at different acidity. International Journal of Food Science & Technology 42(8):948-52.

Guo Q, Su J, Shu X, Yuan F, Mao L, Gao Y. 2020. Development of high methoxyl pectin-surfactant-pea protein isolate ternary complexes: Fabrication, characterization and delivery of resveratrol. Food Chemistry 321:126.

Hasler CM. 1998. Functional foods: their role in disease prevention and health promotion. Food Technology 52:63-147.

Hasler CM. 2005. Regulation of functional foods and nutraceuticals: a global perspective. ames, Iowa: Blackwell Publishing.

Haug A, Høstmark AT, Harstad OM. 2007. Bovine milk in human nutrition–a review. Lipids in Health and Disease 6(1):25.

Hertanto B, Pramono A. 2019. Physical and hedonic properties of cow milk yogurt containing different levels of avocado pulp (Perseaamericana, Mill). IOP Conference Series: Materials Science and Engineering: IOP Publishing. p. 012049.

Holt C, Carver J, Ecroyd H, Thorn D. 2013. Invited review: Caseins and the casein micelle: Their biological functions, structures, and behavior in foods. Journal of Dairy Science 96(10):6127-46.

Hu FB. 2003. Plant-based foods and prevention of cardiovascular disease: an overview. The American Journal of Clinical Nutrition 78(3):544S-51S.

Huan Y, Zhang S, Vardhanabhuti B. 2016. Influence of the molecular weight of carboxymethylcellulose on properties and stability of whey protein-stabilized oil-in-water emulsions. Journal of Dairy Science 99(5):3305-15.

Hui YH, Evranuz EO. 2012. Handbook of Animal-Based Fermented Food and Beverage Technology, 2nd ed. Boca Raton, FL: CRC Press.

Husson F, Le S, Cadoret M. 2020. SensoMineR: Sensory data analysis. R package version 1.25. Retrieved fom.

Im J. 1995. Chemical, physical and sensory properties of frozen desserts formulated to meet consumer preferences. Columbia, MO: University of Missouri - Columbia.

Inoue K, Shiota K, Ito T. 1998. Preparation and properties of ice cream type frozen yogurt. International Journal of Dairy Technology 51(2):44-56.

Insight M-GMRM. 2020. The Future Of Ice Cream Market Report 2021. 2020 Available from: https://store.mintel.com/the-future-of-ice-cream-market-research-report?_ga=2.224052952.210548508.1625632611-1332578360.1625632611.

International Dairy Foods Association. 2017. Dairy Industry Applauds USDA Secretary Perdue for Supporting School Milk Options. 2017 [Accessed 2018 June 10, 2018] Available from: http://www.idfa.org/news-views/news-releases/article/2017/05/01/dairy-industry-applauds-usda-secretary-perdue-for-supporting-school-milk-options.

Isik U, Boyacioglu D, Capanoglu E, Erdil DN. 2011. Frozen yogurt with added inulin and isomalt. Journal of Dairy Science 94(4):1647-56.

Jain VK, Rai DC. 2018. Physicochemical properties of reduced fat, low calorie and protein rich ice cream. Journal of Pharmacognosy and Phytochemistry 7(6):2631-6.

Jandal J. 1996. Comparative aspects of goat and sheep milk. Small ruminant research 22(2):177-85.

Jauhiainen T, Korpela R. 2007. Milk peptides and blood pressure. the Journal of Nutrition 137(3):825S-9S.

Jenssen H, Hancock RE. 2009. Antimicrobial properties of lactoferrin. Biochimie 91(1):19-29.

Jones PJ. 2002. Clinical nutrition: 7. Functional foods—more than just nutrition. Canadian Medical Association Journal 166(12):1555-63.

Jrad Z, Oussaief O, Bouhemda T, Khorchani T, EL‐Hatmi H. 2019. Potential effects of ultrafiltration process and date powder on textural, sensory, bacterial viability, antioxidant properties and phenolic profile of dromedary Greek yogurt. International Journal of Food Science & Technology 54(3):854-61.

Kalra EK. 2003. Nutraceutical-definition and introduction. Aaps Pharmsci 5(3):27-8.

Kemp SE, Hort J, Hollowood T. 2018. Descriptive analysis in sensory evaluation. Hoboken, NJ: Wiley Blackwell.

Kinsella JE, Morr CV. 1984. Milk proteins: physicochemical and functional properties. Critical Reviews in Food Science and Nutrition 21(3):197-262.

Kolida S, Gibson GR. 2011. Synbiotics in Health and Disease. Annual Review of Food Science and Technology 2:373-93.

Kotchabhakdi A. 2018. Developing clean label emulsifier based on whey protein and pectin complexes. Columbia, MO: University of Missouri--Columbia.

Kotilainen L. 2006. Health Enhancing Foods: Opportunities for Strengthening the Sector in Developing Coutries: International Bank for Reconstruction and Development: The World Bank.

Kruel TM. 2004. Development of low-fat and fat-free strawberry ice creams using fat replacers: University of Missouri-Columbia.

Krzeminski A, Großhable K, Hinrichs J. 2011. Structural properties of stirred yoghurt as influenced by whey proteins. LWT-Food Science and Technology 44(10):2134-40.

Lamprecht G, Blochberger K. 2009. Protocol for isolation of vanillin from ice cream and yoghurt to confirm the vanilla beans origin by 13C-EA-IRMS. Food Chemistry 114(3):1130-4.

Lawless HT, Heymann H. 2010. Sensory evaluation of food: principles and practices. Boston, MA: Springer.

Le Dien S, Pagès J. 2003. Hierarchical multiple factor analysis: application to the comparison of sensory profiles. Food quality and preference 14(5-6):397-403.

Lê S, Worch T. 2018. Analyzing sensory data with R: Chapman and Hall/CRC.

Lever J, Krzywinski M, Altman N. 2017. Points of significance: Principal component analysis. Nature Methods 14(7):641-3.

Levinson Y, Ish-Shalom S, Segal E, Livney YD. 2016. Bioavailability, rheology and sensory evaluation of fat-free yogurt enriched with VD 3 encapsulated in re-assembled casein micelles. Food & Function 7(3):1477-82.

Li Z, Marshall R, Heymann H, Fernando L. 1997. Effect of Milk Fat Content on Flavor Perception of Vanilla Ice Cream. Journal of Dairy Science 80(12):3133-41.

Lin Q, Liang R, Zhong F, Ye A, Singh H. 2018. Interactions between octenyl-succinic-anhydride-modified starches and calcium in oil-in-water emulsions. Food Hydrocolloids 77:30-9.

Lin T-N. 2012. Sensory Analysis, Instrumental Analysis, and Consumers' Acceptance Toward Multifunctional Ice Creams. Columbia, MO: University of Missouri, Columbia.

Liou B-K. 2006. Sensory analysis of low fat strawberry ice creams prepared with different flavor chemicals and fat mimetics. Columbia, MO University of Missouri-Columbia.

MacDonald KE. 2018. Analysis of Frozen Desserts using Low-Temperature Scanning Electron Microscopy (LT-SEM). Clemson University.

Mark-Herbert C. 2002. Functional foods for added value. Swedish University of Agricultural Sciences.

Market Data Forcast. 2021. Europe Frozen Dessert Market Segmentation By Product Type (Sherbet, Frozen Yogurt, Frozen Ice Cream, Frozen Tofu, Frozen Cakes, Mousse, Frozen Novelties)...Size, Share, Trends, Growth, Forecast (2021-2026). Market Data Forcast; 2021 Available from: https://www.marketdataforecast.com/market-reports/europe-rozen-desserts-market.

Market Research Future. 2021. Global Frozen Dessert Market: Information By Product Type (Ice Cream, Yogurts, Cakes, Others), Category...and Region (North America, Europe, Asia-Pacific and Rest of the World) - Forecast till 2027. Market Research Future; 2021 Available from: https://www.marketresearchfuture.com/reports/frozen-dessert-market-1520.

Marshall RT, Goff HD, Hartel RW. 2003. Ice Cream, 6 ed. New York, NY: Kluwer Academic/ Plenum Published.

Marteau P, Boutron-Ruault M. 2002. Nutritional advantages of probiotics and prebiotics. British Journal of Nutrition 87(S2):S153-S7.

Martini MC, Lerebours EC, Lin W-J, Harlander SK, Berrada NM, Antoine JM, Savaiano DA. 1991. Strains and species of lactic acid bacteria in fermented milks (yogurts): effect on in vivo lactose digestion. The American Journal of Clinical Nutrition 54(6):1041-6.

Matak KE, Wilson JH, Duncan SE, Wilson EJ, Hackney CR, Sumner SS. 2003. The influence of lactose hydrolysis on the strength and sensory characteristics of vanilla ice cream. Transactions of the ASAE 46(6):1589.

McClements DJ, Decker EA, Weiss J. 2007. Emulsion‐based delivery systems for lipophilic bioactive components. Journal of Food Science 72(8):R109-R24.

McClements DJ, Gumus CE. 2016. Natural emulsifiers—Biosurfactants, phospholipids, biopolymers, and colloidal particles: Molecular and physicochemical basis of functional performance. Advances in Colloid and Interface Science 234:3-26.

McKight PE, Najab J. 2010. Kruskal‐wallis test. The corsini encyclopedia of psychology:1-.

Mendes AN, Kelber N, Filgueiras LA, Costa CSCd, Porto CPM, Pierucci APTR, Nele M. 2018. Evaluation of surfactant activity and emulsifying of Pea protein isolate (Pisum sativum L.) obtained by the spray dryer. Matéria (Rio de Janeiro) 23(4).

Meyer SB, Medina-Solórzano A, Dahl WJ. 2012. Shopping for health: Yogurt. EDIS 2012(4).

Mills S, Ross R, Hill C, Fitzgerald G, Stanton C. 2011. Milk intelligence: Mining milk for bioactive substances associated with human health. International Dairy Journal 21(6):377-401.

Monge A, Cardovo T, Barreiro E, Huenchunir P, Pinzon R, Mora G. 2008. Functional Foods - Reflexions of a scientist regarding a market in expansion Revista de la Sociedad Química del Perú 74(2):138-47.

Mordor Intelligence. 2021. Frozen Desserts Market - Growth, Trends, Covid-19 Impact, And Forecasts (2021 - 2026). Mordor Intelligence; 2021 Available from: https://www.mordorintelligence.com/industry-reports/frozen-dessert-market.

Mostafavi FS. 2019. Evaluating the effect of fat content on the properties of vanilla ice cream using principal component analysis. Journal of Food Measurement and Characterization 13(3):2417-25.

Muzammil HS, Javed I, Rasco B, Zahoor T. 2015. Viability of Probiotics in Frozen Yogurt with different levels of Overrun and Glycerol. International Journal of Agriculture & Biology 17(3).

Nachay K. 2014. Expanding Opportunities for Yogurt. Food Technology 68(2):46-+.

Næs T. 1996. Multivariate analysis of data in sensory science. New york, NY: Elsevier.

Narayan KMV, Boyle JP, Thompson TJ, Sorensen SW, Williamson DF. 2003. Lifetime Risk for Diabetes Mellitus in the United States. JAMA 290(14):1884-90.

Narayanan P, Chinnasamy B, Jin L, Clark S. 2014. Use of just-about-right scales and penalty analysis to determine appropriate concentrations of stevia sweeteners for vanilla yogurt. Journal of Dairy Science 97(6):3262-72.

National Center for Health Statisitics. 2017. Health, United States Spotlight. CDC: Department of Health and Human Services; 2017 [Accessed 2019 2/19/2019] Available from: https://www.cdc.gov/nchs/hus/spotlight/2017-december.htm.

Nixon SC. 2012. Development of a High Protein Frozen Dessert. [Master of Engineering (ME) Masters]. Hamilton, New Zealand: University of Waikato.

O'Sullivan MG. 2011. 29 - The stability and shelf life of meat and poultry. In: Kilcast D, Subramaniam P, editors. Food and Beverage Stability and Shelf Life: Woodhead Publishing. p. 793-816.

Ordonez A, Jeon I, Roberts H. 2000. Manufacture Of Frozen Yogurt With Ultrafiltered Milk And Probiotic Lactic Acid Bacteria. Journal of Food Processing and Preservation 24(2):163-76.

Ortinau LC, Hoertel HA, Douglas SM, Leidy HJ. 2014. Effects of high-protein vs. high-fat snacks on appetite control, satiety, and eating initiation in healthy women. Nutrition Journal 13(97):(29 September 2014).

Ozdemir C, Arslaner A, Ozdemir S, Allahyari M. 2015. The production of ice cream using stevia as a sweetener. Journal of Food Science and Technology 52(11):7545-8.

Özer B. 2006. Production of concentrated products. Fermented Milks:128-55.

Palazzo A, Carvalho M, Efraim P, Bolini H. 2011. The determination of isosweetness concentrations of sucralose, rebaudioside and neotame as sucrose substitutes in new diet chocolate formulations using the time‐intensity analysis. Journal of Sensory Studies 26(4):291-7.

Pelczar M. 1986. Microbiology, 5/Ed. McGraw Hill, New York.

Peleg M. 2017. The basics of solid foods rheology. Food Texture:3-33.

Pereira da Costa M, Conte-Junior Carlos A. 2015. Chromatographic Methods for the Determination of Carbohydrates and Organic Acids in Foods of Animal Origin. Comprehensive Reviews in Food Science and Food Safety 14(5):586-600.

Pereira PC. 2014. Milk nutritional composition and its role in human health. Nutrition 30(6):619-27.

Peres J, Esmerino E, da Silva AL, Racowski I, Bolini H. 2018. Sensory profile, drivers of liking, and influence of information on the acceptance of low‐calorie synbiotic and probiotic chocolate ice cream. Journal of Food Science 83(5):1350-9.

Peryam DR, Pilgrim FJ. 1957. Hedonic scale method of measuring food preferences. Food Technology 1(1).

Phelan M, Aherne A, FitzGerald RJ, O'Brien NM. 2009. Casein-derived bioactive peptides: biological effects, industrial uses, safety aspects and regulatory status. International Dairy Journal 19(11):643-54.

Pon S, Lee W, Chong G. 2015. Textural and rheological properties of stevia ice cream. International Food Research Journal 22(4).

Rahman MA, Hossain MF, Hossain M, Ahmmed R. 2020. Employing PCA and t-statistical approach for feature extraction and classification of emotion from multichannel EEG signal. Egyptian Informatics Journal 21(1):23-35.

Reid G, Howard J, Gan BS. 2001. Can bacterial interference prevent infection? Trends in Microbiology 9(9):424-8.

Rezaei R, Khomeiri M, Aalami M, Kashaninejad M. 2014. Effect of inulin on the physicochemical properties, flow behavior and probiotic survival of frozen yogurt. Journal of Food Science and Technology 51(10):2809-14.

Rice BH. 2014. Dairy and cardiovascular disease: a review of recent observational research. Current Nutrition Reports 3(2):130-8.

Rice BH, Quann EE, Miller GD. 2013. Meeting and exceeding dairy recommendations: effects of dairy consumption on nutrient intakes and risk of chronic disease. Nutrition Reviews 71(4):209-23.

Rizzoli R, Biver E. 2018. Effects of fermented milk products on bone. Calcified Tissue international 102(4):489-500.

Robert P, Escoufier Y. 1976. A Unifying Tool for Linear Multivariate Statistical Methods: The RV-Coefficient. Journal of the Royal Statistical Society. Series C (Applied Statistics) 25(3):257-65.

Rousseau B, Ennis DM, Rossi F. 2012. Internal preference mapping and the issue of satiety. Food Quality and Preference 24(1):67-74.

Salam A, Salama F, Youssef A. 1981. Manufacture of a high quality ice-cream. I. Gross composition of plain ice-cream. Egyptian Journal of Dairy Science 1(1):10.

Şanlıdere Aloğlu H, Öner Z. 2013. The effect of treating goat's milk with transglutaminase on chemical, structural, and sensory properties of labneh. Small Ruminant Research 109(1):31-7.

Seckin AK, Ozkilinc AY. 2011. Effect of some prebiotics usage on quality properties of concentrated yogurt. Journal of Animal and Veterinary Advances 10(9):1117-23.

Serventi L. 2020. Soaking Water Composition. Upcycling Legume Water: from wastewater to food ingredients: Springer. p. 27-39.

Shah N. 2000. Probiotic bacteria: selective enumeration and survival in dairy foods. Journal of Dairy Science 83(4):894-907.

Shewale RN, Sawale PD, Khedkar C, Singh A. 2014. Selection criteria for probiotics: A review. International Journal of Probiotics & Prebiotics 9(1/2):17.

Shimizu T. 2002. Newly established regulation in Japan: foods with health claims. Asia Pacific Journal of Clinical Nutrition 11(2):S94-S6.

Song D, Ibrahim S, Hayek S. 2012. Recent application of probiotics in food and agricultural science. Probiotics 10:1-34.

Soukoulis C, Chandrinos I, Tzia C. 2008. Study of the functionality of selected hydrocolloids and their blends with κ-carrageenan on storage quality of vanilla ice cream. LWT - Food Science and Technology 41(10):1816-27.

Soukoulis C, Fisk ID, Bohn T. 2014. Ice cream as a vehicle for incorporating health-promoting ingredients: conceptualizationand overview of quality and storage stability aspects. Comprehensive Reviews in Food Science and Food Safety 13(4).

Soukoulis C, Panagiotidis P, Koureli R, Tzia C. 2007. Industrial yogurt manufacture: monitoring of fermentation process and improvement of final product quality. Journal of dairy science 90(6):2641-54.

Soukoulis C, Tzia C. 2008. Impact of the acidification process, hydrocolloids and protein fortifiers on the physical and sensory properties of frozen yogurt. International Journal of Dairy Technology 61(2):170-7.

Soukoulis C, Tzia C. 2010. Response surface mapping of the sensory characteristics and acceptability of chocolate ice cream containing alternate sweetening agents. Journal of sensory studies 25(1):50-75.

Spence JT. 2006. Challenges related to the composition of functional foods. Journal of Food Composition and Analysis 19:S4-S6.

Stampanoni Koeferli CR, Piccinali P, Sigrist S. 1996. The influence of fat, sugar and non-fat milk solids on selected taste, flavor and texture parameters of a vanilla ice-cream. Food Quality and Preference 7(2):69-79.

Tabachnik B, Fidell L. 1996. Using multivariate statistics. HarperCollins College Publishers New York,NY.

Talwalkar A, Kailasapathy K. 2004. A review of oxygen toxicity in probiotic yogurts: influence on the survival of probiotic bacteria and protective techniques. Comprehensive Reviews in Food Science and Food Safety 3(3):117-24.

Tamime AY. 2007. Microstructure of Frozen Dairy-based Confectionery Products. Oxford, England: Blackwell.

Tamime AY, Robinson RK. 2007. Tamime and Robinson's yoghurt: science and technology. Boca Raton, Fl: Elsevier.

Tang JE, Moore DR, Kujbida GW, Tarnopolsky MA, Phillips SM. 2009. Ingestion of whey hydrolysate, casein, or soy protein isolate: effects on mixed muscle protein synthesis at rest and following resistance exercise in young men. Journal of Applied physiology.

Texture Technologies Corp. 2020. Overview of Texture Profile Analysis. 2020 Available from: https://texturetechnologies.com/resources/texture-profile-analysis#tpa-measurements.

Tharp B, Forrest B, Swan C, Dunning L, Hilmoe M. 1998. Basic factors affecting ice cream meltdown. International Dairy Federation Special Issue (3):54-64.

Torres IC, Janhøj T, Mikkelsen BØ, Ipsen R. 2011. Effect of microparticulated whey protein with varying content of denatured protein on the rheological and sensory characteristics of low-fat yoghurt. International Dairy Journal 21(9):645-55.

U.S. Department of Agriculture. 2015. 2015–2020 Dietary Guidelines for Americans. 8th Edition. 8 ed: U.S. Department of Health and Human Services; 2015 [Accessed 2019 2/19/2019] Available from: https://health.gov/dietaryguidelines/2015/guidelines/executive-summary/.

Uyanık GK, Güler N. 2013. A Study on Multiple Linear Regression Analysis. Procedia - Social and Behavioral Sciences 106:234-40.

Vasiljevic T, Shah NP. 2008. Probiotics—from Metchnikoff to bioactives. International Dairy Journal 18(7):714-28.

Vedamuthu ER. 2006. Starter cultures for yogurt and fermented milks. Manufacturing Yogurt and Fermented Milks:89-116.

Veldhorst M, Smeets A, Soenen S, Hochstenbach-Waelen A, Hursel R, Diepvens K, Lejeune M, Luscombe-Marsh N, Westerterp-Plantenga M. 2008. Protein-induced satiety: Effects and mechanisms of different proteins. Physiology & Behavior 94(2):300-7.

Vesa TH, Marteau P, Korpela R. 2000. Lactose intolerance. Journal of the American College of Nutrition 19(sup2):165S-75S.

Wagner C. 2019. Challenges and strategies for formulating plant-based frozen desserts. IDFA 2019: International Dairy Foods Association.

Warren MM, Hartel RW. 2018. Effects of Emulsifier, Overrun and Dasher Speed on Ice Cream Microstructure and Melting Properties. Journal of Food Science 83(3):639-47.

White CH, Kilara A, Hui Y. 2008. Manufacturing yogurt and fermented milks. Victoria, Australia: John Wiley & Sons.

Yildiz F. 2010. Development and manufacture of yogurt and other functional dairy products. Boca Raton, FL: CRC Press.

Yüksel AK, Yüksel M, Şat İG. 2017. Determination of certain physicochemical characteristics and sensory properties of green tea powder (matcha) added ice creams and detection of their organic acid and mineral contents. GIDA/The Journal of FOOD 42(2).

Zhang H, Metzger LE. 2021. Organic Acids. Handbook of Dairy Foods Analysis: CRC Press. p. 293-306.

Zhang Z, Goff HD. 2004. Protein distribution at air interfaces in dairy foams and ice cream as affected by casein dissociation and emulsifiers. International Dairy Journal 14(7):647-57.

Ziemer CJ, Gibson GR. 1998. An overview of probiotics, prebiotics and synbiotics in the functional food concept: perspectives and future strategies. International Dairy Journal 8(5-6):473-9.

Appendix A – Physico-Chemical ANOVA Tables, Contrasts, & Formulas

Overrun ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value   Pr(>F)
Sample       6  218.8   36.47   7.756 2.38e-05 ***
Residuals   35  164.6    4.70
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                Df Sum Sq Mean Sq F value   Pr(>F)
Sample                           6 218.80   36.47   7.756 2.38e-05 ***
  Sample: Yogurt_Type            1  33.33   33.33   7.088 0.011646 *
  Sample: Concentration_10_15    1  60.51   60.51  12.868 0.001011 **
  Sample: Concentration_10_20    1  33.54   33.54   7.134 0.011400 *
  Sample: Linear_contrast_INT    1  76.74   76.74  16.320 0.000278 ***
  Sample: Quadratic_contrast_INT 1  14.69   14.69   3.124 0.085878 .
Residuals                       35 164.57    4.70
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Melting Rate ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value  Pr(>F)
Sample       6 22.001   3.667   20.99 2.9e-10 ***
Residuals   35  6.116   0.175
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                Df Sum Sq Mean Sq F value   Pr(>F)
Sample                           6 22.001   3.667  20.986 2.90e-10 ***
  Sample: Yogurt_Type            1  0.841   0.841   4.811 0.035007 *
  Sample: Concentration_10_15    1  5.134   5.134  29.384 4.48e-06 ***
  Sample: Concentration_10_20    1  3.340   3.340  19.115 0.000105 ***
  Sample: Linear_contrast_INT    1  0.302   0.302   1.728 0.197277
  Sample: Quadratic_contrast_INT 1  0.064   0.064   0.365 0.549803
Residuals                       35  6.116   0.175
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

pH ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6 18.631  3.1051   483.7 <2e-16 ***
Residuals   35  0.225  0.0064
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                Df Sum Sq Mean Sq F value   Pr(>F)
Sample                           6 18.631  3.1051 483.666  < 2e-16 ***
  Sample: Yogurt_Type            1  2.050  2.0497 319.263  < 2e-16 ***
  Sample: Concentration_10_15    1  0.924  0.9243 143.978 5.87e-14 ***
  Sample: Concentration_10_20    1  2.438  2.4384 379.808  < 2e-16 ***
  Sample: Linear_contrast_INT    1  0.040  0.0400   6.233   0.0174 *
  Sample: Quadratic_contrast_INT 1  0.036  0.0356   5.538   0.0244 *
Residuals                       35  0.225  0.0064
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Titratable Acidity ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6 1.4769 0.24616   236.2 <2e-16 ***
Residuals   35 0.0365 0.00104
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                Df Sum Sq Mean Sq F value   Pr(>F)
Sample                           6 1.4769  0.2462 236.214  < 2e-16 ***
  Sample: Yogurt_Type            1 0.4920  0.4920 472.111  < 2e-16 ***
  Sample: Concentration_10_15    1 0.0078  0.0078   7.456  0.00983 **
  Sample: Concentration_10_20    1 0.2407  0.2407 231.001  < 2e-16 ***
  Sample: Linear_contrast_INT    1 0.1674  0.1674 160.665 1.22e-14 ***
  Sample: Quadratic_contrast_INT 1 0.0415  0.0415  39.854 2.99e-07 ***
Residuals                       35 0.0365  0.0010
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Protein ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6  4.097  0.6828   1.922  0.147
Residuals   14  4.975  0.3553
```

```
                                Df Sum Sq Mean Sq F value Pr(>F)
Sample                           6  4.097  0.6828   1.922 0.1472
  Sample: Yogurt_Type            1  2.354  2.3545   6.626 0.0221 *
  Sample: Concentration_10_15    1  0.011  0.0108   0.030 0.8641
  Sample: Concentration_10_20    1  0.384  0.3844   1.082 0.3159
  Sample: Linear_contrast_INT    1  0.053  0.0533   0.150 0.7043
  Sample: Quadratic_contrast_INT 1  0.040  0.0400   0.113 0.7422
Residuals                       14  4.975  0.3553
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Moisture Content ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6  99.55   16.59   1.006   0.46
Residuals   14 230.95   16.50
```

```
                                Df Sum Sq Mean Sq F value Pr(>F)
Sample                           6  99.55  16.591   1.006  0.460
  Sample: Yogurt_Type            1   2.71   2.707   0.164  0.692
  Sample: Concentration_10_15    1   6.04   6.035   0.366  0.555
  Sample: Concentration_10_20    1   2.48   2.481   0.150  0.704
  Sample: Linear_contrast_INT    1   0.63   0.626   0.038  0.848
  Sample: Quadratic_contrast_INT 1   0.10   0.098   0.006  0.940
Residuals                       14 230.95  16.497
```

Fat ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6  48.79   8.132   2.752 0.0556 .
Residuals   14  41.37   2.955
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                Df Sum Sq Mean Sq F value Pr(>F)
Sample                           6  48.79   8.132   2.752 0.0556 .
  Sample: Yogurt_Type            1   0.52   0.524   0.177 0.6802
  Sample: Concentration_10_15    1   3.72   3.719   1.258 0.2808
  Sample: Concentration_10_20    1   0.81   0.810   0.274 0.6088
  Sample: Linear_contrast_INT    1   0.87   0.875   0.296 0.5949
  Sample: Quadratic_contrast_INT 1   0.86   0.859   0.291 0.5983
Residuals                       14  41.37   2.955
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Fiber ANOVA Table and Orthogonal Contrasts:

```
            Df   Sum Sq   Mean Sq F value Pr(>F)
Sample       6 0.003714 0.0006190   3.611 0.0224 *
Residuals   14 0.002400 0.0001714
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df   Sum Sq   Mean Sq F value  Pr(>F)
Sample                            6 0.003714 0.0006190   3.611 0.02238 *
  Sample: Yogurt_Type             1 0.000022 0.0000222   0.130 0.72419
  Sample: Concentration_10_15     1 0.000075 0.0000750   0.437 0.51907
  Sample: Concentration_10_20     1 0.000003 0.0000028   0.016 0.90052
  Sample: Linear_contrast_INT     1 0.001200 0.0012000   7.000 0.01919 *
  Sample: Quadratic_contrast_INT  1 0.001878 0.0018778  10.954 0.00516 **
Residuals                        14 0.002400 0.0001714
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Ash ANOVA Table and Orthogonal Contrasts:

```
            Df  Sum Sq  Mean Sq F value Pr(>F)
Sample       6 0.00766 0.001276   0.122  0.992
Residuals   14 0.14587 0.010419
```

```
                                 Df  Sum Sq  Mean Sq F value Pr(>F)
Sample                            6 0.00766 0.001276   0.122  0.992
  Sample: Yogurt_Type             1 0.00056 0.000556   0.053  0.821
  Sample: Concentration_10_15     1 0.00301 0.003008   0.289  0.599
  Sample: Concentration_10_20     1 0.00123 0.001225   0.118  0.737
  Sample: Linear_contrast_INT     1 0.00241 0.002408   0.231  0.638
  Sample: Quadratic_contrast_INT  1 0.00000 0.000003   0.000  0.987
Residuals                        14 0.14587 0.010419
```

Carbohydrate ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6   19.8    3.30   0.313   0.92
Residuals   14  147.5   10.54
```

```
                                 Df Sum Sq Mean Sq F value Pr(>F)
Sample                            6  19.80   3.300   0.313  0.920
  Sample: Yogurt_Type             1   0.66   0.657   0.062  0.806
  Sample: Concentration_10_15     1   0.14   0.137   0.013  0.911
  Sample: Concentration_10_20     1   1.77   1.769   0.168  0.688
  Sample: Linear_contrast_INT     1   0.00   0.001   0.000  0.991
  Sample: Quadratic_contrast_INT  1   1.08   1.078   0.102  0.754
Residuals                        14 147.51  10.536
```

Hardness ANOVA Table and Orthogonal Contrasts:

```
            Df  Sum Sq Mean Sq F value   Pr(>F)
Sample       6 3758552  626425   27.84 3.86e-10 ***
Residuals   26  584975   22499
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df  Sum Sq Mean Sq F value   Pr(>F)
Sample                            6 3758552  626425  27.842 3.86e-10 ***
  Sample: Yogurt_Type             1  143533  143533   6.380 0.017976 *
  Sample: Concentration_10_15     1  754807  754807  33.548 4.22e-06 ***
  Sample: Concentration_10_20     1  472766  472766  21.013 0.000101 ***
  Sample: Linear_contrast_INT     1   42494   42494   1.889 0.181080
  Sample: Quadratic_contrast_INT  1   87543   87543   3.891 0.059270 .
Residuals                        26  584975   22499
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Cohesiveness ANOVA Table and Orthogonal Contrasts:

```
            Df  Sum Sq  Mean Sq F value Pr(>F)
Sample       6 0.02627 0.004378   0.645  0.694
Residuals   26 0.17651 0.006789
```

```
                                 Df  Sum Sq  Mean Sq F value Pr(>F)
Sample                            6 0.02627 0.004378   0.645  0.694
  Sample: Yogurt_Type             1 0.00936 0.009363   1.379  0.251
  Sample: Concentration_10_15     1 0.00258 0.002583   0.381  0.543
  Sample: Concentration_10_20     1 0.00581 0.005814   0.856  0.363
  Sample: Linear_contrast_INT     1 0.00041 0.000407   0.060  0.809
  Sample: Quadratic_contrast_INT  1 0.00177 0.001775   0.261  0.613
Residuals                        26 0.17651 0.006789
```

Springiness ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6 0.1472 0.02453   1.315  0.286
Residuals   26 0.4853 0.01866
```

```
                                 Df Sum Sq Mean Sq F value Pr(>F)
Sample                            6 0.1472 0.02453   1.315  0.286
  Sample: Yogurt_Type             1 0.0042 0.00423   0.226  0.638
  Sample: Concentration_10_15     1 0.0417 0.04168   2.233  0.147
  Sample: Concentration_10_20     1 0.0404 0.04040   2.165  0.153
  Sample: Linear_contrast_INT     1 0.0261 0.02611   1.399  0.248
  Sample: Quadratic_contrast_INT  1 0.0109 0.01089   0.583  0.452
Residuals                        26 0.4853 0.01866
```

Gumminess ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value  Pr(>F)
Sample       6 226763   37794    4.77 0.00211 **
Residuals   26 206024    7924
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value  Pr(>F)
Sample                            6 226763   37794   4.770 0.00211 **
  Sample: Yogurt_Type             1  13535   13535   1.708 0.20267
  Sample: Concentration_10_15     1  36025   36025   4.546 0.04260 *
  Sample: Concentration_10_20     1  28065   28065   3.542 0.07108 .
  Sample: Linear_contrast_INT     1   3758    3758   0.474 0.49711
  Sample: Quadratic_contrast_INT  1  12560   12560   1.585 0.21921
Residuals                        26 206024    7924
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Chewiness ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value  Pr(>F)
Sample       6  85755   14292   3.814 0.00737 **
Residuals   26  97429    3747
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value  Pr(>F)
Sample                            6  85755   14292   3.814 0.00737 **
  Sample: Yogurt_Type             1   5528    5528   1.475 0.23543
  Sample: Concentration_10_15     1  13417   13417   3.581 0.06965 .
  Sample: Concentration_10_20     1  12017   12017   3.207 0.08498 .
  Sample: Linear_contrast_INT     1   1246    1246   0.332 0.56919
  Sample: Quadratic_contrast_INT  1   4976    4976   1.328 0.25966
Residuals                        26  97429    3747
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Resilience ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6   4.15  0.6916   1.313  0.286
Residuals   26  13.69  0.5266
```

```
                                Df Sum Sq Mean Sq F value Pr(>F)
Sample                           6  4.150   0.692   1.313 0.2864
  Sample: Yogurt_Type            1  0.118   0.118   0.224 0.6401
  Sample: Concentration_10_15    1  0.259   0.259   0.492 0.4893
  Sample: Concentration_10_20    1  3.305   3.305   6.277 0.0188 *
  Sample: Linear_contrast_INT    1  0.047   0.047   0.090 0.7666
  Sample: Quadratic_contrast_INT 1  0.100   0.100   0.189 0.6671
Residuals                       26 13.691   0.527
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Particle Size (4,3) ANOVA Table and Orthogonal Contrasts:

```
             Df Sum Sq Mean Sq F value Pr(>F)
Sample        6   9094    1516   116.4 <2e-16 ***
Residuals   203   2644      13
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample                            6   9094  1515.7 116.392  < 2e-16 ***
  Sample: Yogurt_Type             1    436   436.3  33.501 2.67e-08 ***
  Sample: Concentration_10_15     1    284   283.9  21.802 5.49e-06 ***
  Sample: Concentration_10_20     1     75    74.6   5.725   0.0176 *
  Sample: Linear_contrast_INT     1    248   247.8  19.032 2.04e-05 ***
  Sample: Quadratic_contrast_INT  1   2696  2696.3 207.048  < 2e-16 ***
Residuals                       203   2644    13.0
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

K (Consistency Coefficient) ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6  5.193  0.8655   3.526 0.0244 *
Residuals   14  3.436  0.2454
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                Df Sum Sq Mean Sq F value  Pr(>F)
Sample                           6  5.193   0.866   3.526 0.02437 *
  Sample: Yogurt_Type            1  3.388   3.388  13.802 0.00231 **
  Sample: Concentration_10_15    1  0.010   0.010   0.040 0.84476
  Sample: Concentration_10_20    1  0.532   0.532   2.166 0.16322
  Sample: Linear_contrast_INT    1  0.929   0.929   3.783 0.07214 .
  Sample: Quadratic_contrast_INT 1  0.026   0.026   0.104 0.75191
Residuals                       14  3.436   0.245
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

N (Flow behavior Index) ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6  0.260 0.04333   4.184 0.0128 *
Residuals   14  0.145 0.01035
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                Df  Sum Sq Mean Sq F value  Pr(>F)
Sample                           6 0.25996 0.04333   4.184 0.01284 *
  Sample: Yogurt_Type            1 0.14315 0.14315  13.825 0.00229 **
  Sample: Concentration_10_15    1 0.00441 0.00441   0.426 0.52447
  Sample: Concentration_10_20    1 0.01472 0.01472   1.421 0.25299
  Sample: Linear_contrast_INT    1 0.08832 0.08832   8.530 0.01118 *
  Sample: Quadratic_contrast_INT 1 0.00001 0.00001   0.001 0.98241
Residuals                       14 0.14496 0.01035
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Appendix B – Organic Acid and Carbohydrate ANOVA Tables, Contrasts, & Formulas

Citric Acid ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value   Pr(>F)
Sample       6 12.005  2.0008   8.038 1.71e-05 ***
Residuals   35  8.712  0.2489
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample                            6 12.005  2.0008   8.038 1.71e-05 ***
  Sample: Yogurt_Type             1  1.512  1.5122   6.075  0.01876 *
  Sample: Concentration_10_15     1  0.280  0.2805   1.127  0.29574
  Sample: Concentration_10_20     1  0.127  0.1266   0.509  0.48047
  Sample: Linear_contrast_INT     1  2.213  2.2126   8.889  0.00519 **
  Sample: Quadratic_contrast_INT  1  2.149  2.1486   8.632  0.00581 **
Residuals                        35  8.712  0.2489
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Pyruvic Acid ANOVA Table and Orthogonal Contrasts:

```
            Df    Sum Sq  Mean Sq F value   Pr(>F)
Sample       6 0.021713 0.003619   21.46 2.15e-10 ***
Residuals   35 0.005902 0.000169
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df    Sum Sq  Mean Sq F value   Pr(>F)
Sample                            6 0.021713 0.003619  21.460 2.15e-10 ***
  Sample: Yogurt_Type             1 0.007210 0.007210  42.757 1.52e-07 ***
  Sample: Concentration_10_15     1 0.004621 0.004621  27.405 7.88e-06 ***
  Sample: Concentration_10_20     1 0.000237 0.000237   1.406  0.24378
  Sample: Linear_contrast_INT     1 0.001844 0.001844  10.933  0.00219 **
  Sample: Quadratic_contrast_INT  1 0.002289 0.002289  13.573  0.00077 ***
Residuals                        35 0.005902 0.000169
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Lactic Acid ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6 167.79  27.965   85.24 <2e-16 ***
Residuals   35  11.48   0.328
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample                            6 167.79  27.965  85.236  < 2e-16 ***
  Sample: Yogurt_Type             1   1.99   1.992   6.071  0.01880 *
  Sample: Concentration_10_15     1   6.99   6.994  21.318 5.07e-05 ***
  Sample: Concentration_10_20     1   1.75   1.750   5.333  0.02694 *
  Sample: Linear_contrast_INT     1  21.03  21.032  64.103 2.02e-09 ***
  Sample: Quadratic_contrast_INT  1   3.17   3.170   9.661  0.00373 **
Residuals                        35  11.48   0.328
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Uric Acid ANOVA Table and Orthogonal Contrasts:

```
            Df    Sum Sq   Mean Sq F value   Pr(>F)
Sample       6 1.811e-04 3.018e-05   16.27 7.63e-09 ***
Residuals   35 6.492e-05 1.855e-06
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df    Sum Sq   Mean Sq F value   Pr(>F)
Sample                            6 1.811e-04 3.018e-05  16.269 7.63e-09 ***
  Sample: Yogurt_Type             1 3.115e-05 3.115e-05  16.795 0.000235 ***
  Sample: Concentration_10_15     1 1.124e-04 1.124e-04  60.625 3.81e-09 ***
  Sample: Concentration_10_20     1 1.683e-05 1.683e-05   9.073 0.004795 **
  Sample: Linear_contrast_INT     1 5.900e-07 5.900e-07   0.316 0.577685
  Sample: Quadratic_contrast_INT  1 1.949e-05 1.949e-05  10.508 0.002611 **
Residuals                        35 6.492e-05 1.850e-06
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Formic Acid ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value   Pr(>F)
Sample       6 0.4443 0.07406    14.3 3.65e-08 ***
Residuals   35 0.1812 0.00518
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample                            6 0.4443 0.07406  14.302 3.65e-08 ***
  Sample: Yogurt_Type             1 0.2005 0.20052  38.724 3.93e-07 ***
  Sample: Concentration_10_15     1 0.0412 0.04121   7.959  0.00783 **
  Sample: Concentration_10_20     1 0.0153 0.01535   2.964  0.09396 .
  Sample: Linear_contrast_INT     1 0.0173 0.01729   3.338  0.07623 .
  Sample: Quadratic_contrast_INT  1 0.0093 0.00934   1.804  0.18788
Residuals                        35 0.1812 0.00518
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Acetic Acid ANOVA Table and Orthogonal Contrasts:

```
            Df  Sum Sq Mean Sq F value Pr(>F)
Sample       6 0.04650 0.00775   34748 <2e-16 ***
Residuals   35 0.00001 0.00000
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df  Sum Sq  Mean Sq F value Pr(>F)
Sample                            6 0.04650 0.007750   34748 <2e-16 ***
  Sample: Yogurt_Type             1 0.00129 0.001292    5791 <2e-16 ***
  Sample: Concentration_10_15     1 0.00181 0.001808    8108 <2e-16 ***
  Sample: Concentration_10_20     1 0.00271 0.002713   12162 <2e-16 ***
  Sample: Linear_contrast_INT     1 0.00452 0.004521   20269 <2e-16 ***
  Sample: Quadratic_contrast_INT  1 0.00904 0.009042   40539 <2e-16 ***
Residuals                        35 0.00001 0.000000
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Propionic Acid ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6 142.39  23.731    1338 <2e-16 ***
Residuals   35   0.62   0.018
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value Pr(>F)
Sample                            6 142.39  23.731  1337.6 <2e-16 ***
  Sample: Yogurt_Type             1   4.82   4.824   271.9 <2e-16 ***
  Sample: Concentration_10_15     1  15.22  15.222   858.0 <2e-16 ***
  Sample: Concentration_10_20     1  20.04  20.041  1129.6 <2e-16 ***
  Sample: Linear_contrast_INT     1  31.55  31.550  1778.3 <2e-16 ***
  Sample: Quadratic_contrast_INT  1   8.58   8.578   483.5 <2e-16 ***
Residuals                        35   0.62   0.018
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Butyric Acid ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value Pr(>F)
Sample       6  95.96  15.994    2079 <2e-16 ***
Residuals   35   0.27   0.008
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value Pr(>F)
Sample                            6  95.96  15.994  2078.5 <2e-16 ***
  Sample: Yogurt_Type             1   5.41   5.411   703.2 <2e-16 ***
  Sample: Concentration_10_15     1   7.60   7.598   987.3 <2e-16 ***
  Sample: Concentration_10_20     1   8.89   8.891  1155.5 <2e-16 ***
  Sample: Linear_contrast_INT     1  23.29  23.289  3026.6 <2e-16 ***
  Sample: Quadratic_contrast_INT  1   7.66   7.657   995.0 <2e-16 ***
Residuals                        35   0.27   0.008
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Sucrose ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value   Pr(>F)
Sample       6  53.12   8.853   21.08 2.72e-10 ***
Residuals   35  14.70   0.420
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample                            6  53.12   8.853  21.083 2.72e-10 ***
  Sample: Yogurt_Type             1   5.47   5.468  13.022 0.000952 ***
  Sample: Concentration_10_15     1   0.64   0.642   1.529 0.224427
  Sample: Concentration_10_20     1  18.16  18.156  43.236 1.36e-07 ***
  Sample: Linear_contrast_INT     1   0.03   0.031   0.073 0.788031
  Sample: Quadratic_contrast_INT  1   5.50   5.499  13.095 0.000926 ***
Residuals                        35  14.70   0.420
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Lactose ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value   Pr(>F)
Sample       6 272.48   45.41   44.83 5.34e-15 ***
Residuals   35  35.46    1.01
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample                            6 272.48   45.41  44.827 5.34e-15 ***
  Sample: Yogurt_Type             1  67.83   67.83  66.959 1.22e-09 ***
  Sample: Concentration_10_15     1  18.28   18.28  18.049 0.000151 ***
  Sample: Concentration_10_20     1  55.41   55.41  54.696 1.19e-08 ***
  Sample: Linear_contrast_INT     1   0.22    0.22   0.219 0.642759
  Sample: Quadratic_contrast_INT  1  28.71   28.71  28.341 6.02e-06 ***
Residuals                        35  35.46    1.01
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Glucose ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value   Pr(>F)
Sample       6 25.476   4.246    20.6 3.71e-10 ***
Residuals   35  7.215   0.206
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample                            6 25.476   4.246  20.598 3.71e-10 ***
  Sample: Yogurt_Type             1  7.708   7.708  37.393 5.45e-07 ***
  Sample: Concentration_10_15     1  0.001   0.001   0.007 0.934522
  Sample: Concentration_10_20     1 14.378  14.378  69.751 7.55e-10 ***
  Sample: Linear_contrast_INT     1  0.220   0.220   1.067 0.308648
  Sample: Quadratic_contrast_INT  1  3.048   3.048  14.786 0.000487 ***
Residuals                        35  7.215   0.206
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Galactose ANOVA Table and Orthogonal Contrasts:

```
            Df Sum Sq Mean Sq F value  Pr(>F)
Sample       6  18.64  3.1071   4.609 0.00151 **
Residuals   35  23.59  0.6741
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
                                 Df Sum Sq Mean Sq F value   Pr(>F)
Sample                            6 18.643   3.107   4.609 0.001512 **
  Sample: Yogurt_Type             1  1.327   1.327   1.969 0.169345
  Sample: Concentration_10_15     1  2.955   2.955   4.384 0.043596 *
  Sample: Concentration_10_20     1 10.066  10.066  14.932 0.000461 ***
  Sample: Linear_contrast_INT     1  0.253   0.253   0.376 0.543781
  Sample: Quadratic_contrast_INT  1  3.440   3.440   5.103 0.030221 *
Residuals                        35 23.595   0.674
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Appendix C – Organic Acid & Carbohydrate Standard Curve Concentrations & Area Counts

Table C-1: Citric acid standard curve concentrations and area counts:

Citric Acid Concentration (µg/ml)	Succinic Acid Concentration* (µg/ml)	Citric Acid Area (220 nm)	Succinic Acid Area* (220 nm)	Ext/Int Concentration	Ext/Int Area Count
900.972	145.77	12363	1071.6	6.180768	11.53695
283.3402	87.3805	4320.6	662.1	3.242602	6.5256
158.6539	71.0477	2583.4	554.2	2.233063	4.661494
42.89869	41.6486	640.7	296.7	1.030014	2.15942
26.80133	36.4711	375.2	264.3	0.734864	1.419599

***Note:** Succinic acid is the internal standard

Table C-2: Pyruvic acid standard curve concentrations and area counts:

Pyruvic Acid Concentration (µg/ml)	Succinic Acid Concentration* (µg/ml)	Pyruvic Acid Area (220 nm)	Succinic Acid Area* (220 nm)	Ext/Int Concentration	Ext/Int Area Count
15.102	295.51872	1802.7	1531.1	0.051103362	1.17738
12.0816	295.1172	1458	1498.4	0.040938312	0.97303
8.85984	293.1096	1200.3	1562.7	0.030227055	0.76809
5.23536	285.0792	699.2	1513	0.018364581	0.46212
1.61088	281.064	245.8	1459	0.005731364	0.16847

***Note:** Succinic acid is the internal standard

Table C-3: Lactic acid standard curve concentrations and area counts:

Lactic Acid Concentration (µg/ml)	Succinic Acid Concentration* (µg/ml)	Lactic Acid Area (220 nm)	Succinic Acid Area* (220 nm)	Ext/Int Concentration	Ext/Int Area Count
470.8008	101.932	3322.5	1575	4.618794	2.109524
200.0904	72.2874	1364.9	1079.4	2.767985	1.264499
129.4702	61.1589	872.2	823.9	2.116947	1.058624
47.08008	40.7726	314.3	432.7	1.154699	0.726369
1.0849	21.2016	14.4	197.9	0.051171	0.072764

***Note:** Succinic acid is the internal standard

Table C-4: Uric acid standard curve concentrations and area counts:

Uric Acid Concentration (µg/ml)	Succinic Acid Concentration* (µg/ml)	Uric Acid Area (220 nm)	Succinic Acid Area* (220 nm)	Ext/Int Concentration	Ext/Int Area Count
20.03424	1116.96	9505.4	9434.2	0.017936	1.007547
16.0392	1116.96	7584.6	8995.1	0.01436	0.843192
12.02448	1116.96	5696.3	9393.7	0.010765	0.606396
8.00976	1116.96	3799.9	9171	0.007171	0.414339
3.99504	1116.96	1951.2	9188	0.003577	0.212364

***Note:** Succinic acid is the internal standard

Table C-5: Formic acid standard curve concentrations and area counts:

Formic Acid Concentration (µg/ml)	Succinic Acid Concentration* (µg/ml)	Formic Acid Area (220 nm)	Succinic Acid Area* (220 nm)	Ext/Int Concentration	Ext/Int Area Count
152.4096	310.653	1887	2449.3	0.490611	0.770424
85.34938	273.375	1067.8	2097.3	0.312207	0.509131
58.93171	256.806	813.1	2271.7	0.229479	0.357926
20.32128	227.812	356.1	1929.3	0.089202	0.184575
2.032128	215.386	91	1992	0.009435	0.045683

***Note:** Succinic acid is the internal standard

Table C-6: Acetic acid standard curve concentrations and area counts:

Acetic Acid Concentration (µg/ml)	Succinic Acid Concentration* (µg/ml)	Acetic Acid Area (220 nm)	Succinic Acid Area* (220 nm)	Ext/Int Concentration	Ext/Int Area Count
116.0512	511.0729	906	3843	0.227074	0.235753
51.80857	463.2897	406	3524	0.111828	0.11521
24.86811	440.4368	212	3327	0.056462	0.063721
10.36171	425.8941	29	3163.7	0.024329	0.009166
2.072343	417.584	8.6	3615	0.004963	0.002379

***Note:** Succinic acid is the internal standard

Table C-7: Propionic acid standard curve concentrations and area counts:

Propionic Acid Concentration (µg/ml)	Succinic acid Concentration* (µg/ml)	Propionic Acid Area (220 nm)	Succinic Acid Area* (220 nm)	Ext/Int Concentration	Ext/Int Area Count
300.81	525.8237	1292.7	2434.5	0.572074	0.530992
115.8028	499.1103	855	4202	0.232018	0.203475
51.69767	452.4455	368	3631	0.114263	0.101349
33.08651	436.2143	235	3460	0.075849	0.067919
2.067907	407.8096	13	3261	0.005071	0.003987

***Note:** Succinic acid is the internal standard

Table C-8: Butyric acid standard curve concentrations and area counts:

Butyric Acid Concentration (µg/ml)	Succinic acid Concentration* (µg/ml)	Butyric Acid Area (220 nm)	Succinic Acid Area* (220 nm)	Ext/Int Concentration	Ext/Int Area Count
320.448	500.968	1194.5	1820	0.639658	0.656319
80.54438	474.331	734	3932	0.169806	0.186673
50.34024	450.11	427	3689	0.11184	0.11575
24.16332	427.907	208	3805	0.056469	0.054665
10.06805	413.778	44.4	3618	0.024332	0.012272

***Note:** Succinic acid is the internal standard

Table C-9: Sucrose standard curve concentrations and area counts:

Sucrose Concentration (mg/ml)	Fructose Concentration* (mg/ml)	Sucrose Area	Fructose Area*	Ext/Int Concentration	Ext/Int Area count
2.06824	0.76076	35349.4	3573.4	2.71865	9.892371
1.34536	0.64064	23154.6	3391.9	2.100025	6.826439
0.9538	0.55055	16257.8	2994.3	1.732449	5.429583
0.64256	0.48048	6363.6	2157.7	1.337329	2.949252
0.37148	0.394394	598.2	373.1	0.941901	1.603324

***Note:** Fructose is the internal standard

Table C-10: Lactose standard curve concentrations and area counts:

Lactose Concentration (mg/ml)	Fructose Concentration* (mg/ml)	Lactose Area	Fructose Area*	Ext/Int Concentration	Ext/Int Area count
1.94544	0.73146	59789.3	6903.9	2.659667	8.660221
1.4616	0.6513	24194.8	3565.6	2.244127	6.785618
0.82656	0.52104	12970	2900.5	1.586366	4.471643
0.4032	0.4008	4843.7	1949.3	1.005988	2.484841
0.03024	0.23046	357.5	1448	0.131216	0.246892

***Note:** Fructose is the internal standard

Table C-11: Glucose standard curve concentrations and area counts:

Glucose Concentration (mg/ml)	Fructose Concentration* (mg/ml)	Glucose Area	Fructose Area*	Ext/Int Concentration	Ext/Int Area count
0.136144	0.31408	2345.7	1448.9	0.433469	1.618952
0.11176	0.3016	1273.2	984.3	0.370557	1.293508
0.087376	0.2808	992.2	1020.2	0.311168	0.972554
0.05588	0.25584	793.3	1279.5	0.218418	0.620008
0.02032	0.2392	151.4	1082.8	0.08495	0.139823

***Note:** Fructose is the internal standard

Table C-12: Galactose standard curve concentrations and area counts:

Galactose Concentration (mg/ml)	Fructose Concentration* (mg/ml)	Galactose Area	Fructose Area*	Ext/Int Concentration	Ext/Int Area count
0.47188	0.91455	2583.1	5016.3	0.51597	0.514941
0.39156	0.87234	2098.2	5135.6	0.448862	0.40856
0.3012	0.82008	1990.8	5542.3	0.367281	0.359201
0.196784	0.75375	1247.1	4903.5	0.261073	0.254329
0.038152	0.63114	212.6	3625.2	0.060449	0.058645

***Note:** Fructose is the internal standard

Appendix D – Descriptive Analysis Consent Forms and Ballot

INFORMED CONSENT FOR DESCRIPTIVE TEST
By participating in this research project, I consent to being a volunteer in the project, and I understand the following:

PROJECT BACKGROUND: This project involves gathering human sensory data on frozen desserts formulated with various types of yogurts. The data will be collected for analysis and may be published. You must be at least 18 years of age to participate.

PURPOSE: The purpose of this sensory test is to study the consumer perceived characteristics of frozen dessert formulated with various yogurts at different concentrations.

VOLUNTARY: This sensory test is entirely voluntary. You may refuse to answer any question or choose to withdraw from participation at any time without any penalty or loss of benefits to which you are otherwise entitled.

WHAT DO YOU DO? You will be asked to participate in a sensory panel.

BENEFITS: Frozen desserts can act as a vehicle to deliver essential nutrients, such as minerals and proteins, that are reduced during manufacturing. Your participation in this sensory test will allow us to better understand the flavor characteristics of frozen desserts that have been formulated with various yogurts that will improve the nutrient density of the product. You will receive a voucher for 1 free scoop of ice cream from Buck's Ice Cream Parlor for every session you participate within the project.
RISKS: The expected risks are none other than those encountered in normal daily food consumption. All product samples have been prepared under sanitary conditions in a health-department-inspected chocolate-production facility. Because the manufacturing facility uses milk, if you have a milk allergy, please do not participate in this study!

CONFIDENTIALITY: Your confidentiality will be maintained in that participation is anonymous. The data will only be reported in aggregate form. Thank you for your assistance in better understanding frozen desserts formulated with yogurt. Although great strides have been made in the instrumental analysis of foods, the development of new foods still requires the human sensory response and feedback.

Your efforts are greatly appreciated!!

If you have any questions regarding the study, please contact Dr. Ingolf Gruen at (573) 882-6746. If you have questions regarding your rights as a participant in research, please feel free to contact the Institutional Review Board at (573) 882-3181.

Score Sheet in Frozen Dessert Descriptive Test

This is a descriptive test of yogurt flavored frozen desserts. Before you begin this test, please make sure you have a cup of water, a dish of references, a spit-out cup, some spoons and papers. If you lack something or want more, please turn on the switch once or inform me.

Direction:

1) Please masticate a piece of cracker and then rinse your mouth with water before you start the test.

2) Record the three-digit sample number on your ballot. Mark a vertical line on the horizontal line that is presented for the perceived intensity of the attribute by comparing to the reference.

3) Open the deli cup of references and taste them to make sure you figure out the intensity of each reference provided for each attribute. Rinse your mouth with water between each reference.

4) Open the deli cup containing the ice cream sample, scrape the central part of the ice cream three times and evaluate "APPEARANCE."

5) Scoop a sample of ice cream onto your spoon and evaluate "SCOOPABILITY."

6) Place the ice cream sample in your mouth and evaluate "THE RATE OF MELT" by using a timer. Then key into the second which you got.

7) Place the ice cream sample in your mouth and evaluate "FLAVOR" and "TEXTURE."

8) Please masticate a piece of cracker and then rinse

9) Expectorate or swallow the sample and evaluate the "AFTERTASTE."

10) Mark a vertical line on the horizontal line that is presented for the perceived intensity of the attribute by comparing to the reference.

11) If you are unclear about any attribute, please go back to taste and check the reference.

Product Code: **Panelist #_____**

APPEARANCE

Sheen

Low High

SCOOPABILITY

Gooeyness

Low High

Hardness

Low High

RATE OF MELT _____sec.

TEXTURE

Creaminess

Low High

Denseness

Low High

Iciness

Low High

Smoothness

Low High

Gumminess

Low High

Mouth coating

Low High

FLAVOR

Sourness flavor

Low High

Fatty flavor

Low High

Bitterness flavor

Low High

Alkaline flavor

Low High

Sweetness flavor

Low High

Milky flavor

Low High

AFTERTASTE

Sourness aftertaste

Low High

Fatty aftertaste

Low High

Bitterness aftertaste

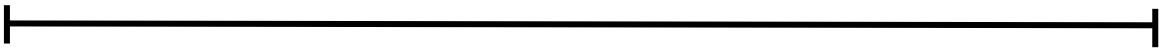
Low High

Alkaline aftertaste

Low High

Sweetness aftertaste

Low High



Milky aftertaste

Low High

Appendix E – Distribution Order of Treatments for Sensory Studies

Legend:

Sample Three-Digit Code	Treatment	Treatment Description
130	GFYC	80% ice cream/ 20% Greek yogurt
200	CTRL	Control ice cream (no yogurt added)
411	GFYA	90% Ice cream/ 10% Greek yogurt
594	FYB	85% ice cream/ 15% regular yogurt
659	FYA	90% ice cream/ 10% regular yogurt
892	GFYB	85% ice cream/ 15% Greek yogurt
989	FYC	80% ice cream/ 20% regular yogurt

Descriptive Analysis Distribution Order (14X14 Williams Latin Square Design):

Replication 1A*:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
1	130	594	411	659	200	659	200
2	989	411	130	200	594	200	892
3	411	130	200	594	200	659	411
4	594	659	130	659	411	989	200
5	659	989	659	892	594	892	130
6	892	892	989	594	659	130	659
	200	411	200	130	411	594	989
7	130	989	594	411	892	200	892
8	989	892	659	892	659	594	594
9	411	200	989	200	130	411	594
10	594	130	892	989	892	411	989
11	659	659	594	989	130	892	411
	892	594	892	130	989	989	659
12	200	200	411	411	989	130	130

*Note: Grey rows represent panelist sequences that were not used for the descriptive analysis.

Replication 1B*:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
1	989	411	892	989	892	130	594
2	411	892	130	989	594	659	659
3	659	989	989	130	892	594	892
4	892	200	892	411	594	989	130
5	594	411	130	200	989	200	411
6	989	594	411	130	200	411	200
	659	130	659	594	989	892	892
7	200	989	411	659	130	659	594
8	130	130	989	411	411	200	200
9	130	892	594	892	659	989	659
10	200	659	200	659	411	594	130
11	892	200	594	200	130	411	989
	411	659	200	594	200	130	411
12	594	594	659	892	659	892	989

*Note: Grey rows represent panelist sequences that were not used for the descriptive analysis.

Replication 2A*:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
1	130	200	594	130	594	659	200
	989	892	892	411	989	659	411
2	411	989	659	892	130	989	200
3	594	130	594	200	200	130	659
4	659	200	411	594	892	594	989
5	892	989	989	892	411	411	659
6	200	594	659	594	411	130	892
	130	659	200	411	130	989	594
7	989	892	411	989	659	892	130
8	411	659	892	200	989	594	892
9	594	594	200	130	659	200	411
10	659	411	130	989	200	892	130
11	892	411	989	659	892	200	989
12	200	130	130	659	594	411	594

*Note: Grey rows represent panelist sequences that were not used for the descriptive analysis.

Replication 2B*:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
1	411	659	989	411	892	892	989
	200	659	594	130	594	200	130
2	892	130	411	594	659	594	200
3	659	411	411	892	989	989	892
4	130	892	200	989	130	411	659
5	659	130	200	200	594	130	594
6	200	989	130	892	659	989	411
	892	594	989	200	892	659	411
7	411	200	659	130	200	594	594
8	594	989	130	411	200	659	130
9	130	892	659	989	411	892	989
10	989	594	892	594	411	200	659
11	594	411	594	659	130	130	200
12	989	200	892	659	989	411	892

*Note: Grey rows represent panelist sequences that were not used for the descriptive analysis.

Replication 3A*:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
8	130	411	411	892	594	200	659
3	989	594	200	659	892	130	989
2	411	892	130	200	411	989	594
4	594	659	989	130	200	659	892
5	659	130	594	659	989	594	200
6	892	200	989	989	200	594	892
7	200	989	892	594	989	659	200
1	130	659	659	594	594	411	989
9	989	892	200	200	892	989	411
10	411	130	594	411	659	892	130
11	594	411	659	130	130	411	659
12	659	594	130	411	659	130	594
	892	200	411	989	130	892	411
	200	989	892	892	411	200	130

*Note: Grey rows represent panelist sequences that were not used for the descriptive analysis.

Replication 3B*:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
8	989	130	892	659	200	594	989
3	659	200	594	892	411	411	130
2	892	659	200	130	989	659	594
4	594	989	411	200	130	892	411
5	411	892	130	989	411	200	892
6	659	411	130	130	659	411	594
7	130	892	659	411	594	130	411
1	130	200	411	892	892	989	200
9	594	130	659	411	130	594	659
10	200	659	989	594	892	989	200
11	892	594	200	989	989	200	892
12	411	989	892	200	200	892	989
	200	594	989	659	594	130	659
	989	411	594	594	659	659	130

*Note: Grey rows represent panelist sequences that were not used for the descriptive analysis.

Consumer Preference (Hedonic) Study Distribution Order (7X14 Williams Latin Square Design):

Replication 1A:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
1	130	411	200	659	892	594	989
2	130	200	411	892	659	989	594
3, 100	989	594	892	659	200	411	130
4	989	892	594	200	659	130	411
5	411	130	659	200	594	892	989
6	411	659	130	594	200	989	892
7	594	989	659	892	411	200	130
8	594	659	989	411	892	130	200
9	659	411	594	130	989	200	892
10	659	594	411	989	130	892	200
11	892	989	200	594	130	659	411
12	892	200	989	130	594	411	659
13	200	130	892	411	989	659	594
14	200	892	130	989	411	594	659

Replication 2A:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
15	130	411	200	989	659	892	594
16	130	200	411	659	989	594	892
17	989	411	892	130	594	200	659
18	989	892	411	594	130	659	200
19, 101	411	130	989	200	892	659	594
20	411	989	130	892	200	594	659
21	594	659	892	200	989	130	411
22	594	892	659	989	200	411	130
23	659	594	200	892	130	989	411
24	659	200	594	130	892	411	989
25	892	989	594	411	659	130	200
26	892	594	989	659	411	200	130
27	200	130	659	411	594	989	892
28	200	892	130	989	411	594	659

Replication 3A:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
29, 99	130	989	659	594	411	200	892
30	130	659	989	411	594	892	200
31	989	130	594	659	200	411	892
32	989	594	130	200	659	892	411
33	411	659	892	130	200	989	594
34	411	892	659	200	130	594	989
35	594	989	200	130	892	659	411
36	594	200	989	892	130	411	659
37	659	130	411	989	892	594	200
38	659	411	130	892	989	200	594
39	892	411	200	659	594	130	989
40	892	200	411	594	659	989	130
41	200	594	892	989	411	130	659
42	200	892	594	411	989	659	130

Replication 1B:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
43	130	594	200	989	411	659	892
44	130	200	594	411	989	892	659
45	989	594	659	130	892	200	411
46	989	659	594	892	130	411	200
47	411	892	200	659	130	989	594
48	411	200	892	130	659	594	989
49	594	130	989	200	659	411	892
50	594	989	130	659	200	892	411
51	659	989	892	594	411	130	200
52	659	892	989	411	594	200	130
53	892	411	659	200	989	130	594
54	892	659	411	989	200	594	130
55	200	130	411	594	892	989	659
56	200	411	130	892	594	659	989

Replication 2B:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
57	130	989	411	594	892	659	200
58	130	411	989	892	594	200	659
59	989	130	594	411	659	892	200
60	989	594	130	659	411	200	892
61	411	130	892	989	200	594	659
62	411	892	130	200	989	659	594
63	594	989	659	130	200	411	892
64	594	659	989	200	130	892	411
65	659	594	200	989	892	130	411
66	659	200	594	892	989	411	130
67	892	411	200	130	659	989	594
68	892	200	411	659	130	594	989
69	200	659	892	594	411	989	130
70	200	892	659	411	594	130	989

Replication 3B:

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
71	130	411	892	200	594	989	659
72	130	892	411	594	200	659	989
73	989	659	200	594	411	892	130
74	989	200	659	411	594	130	892
75	411	130	200	892	989	594	659
76	411	200	130	989	892	659	594
77	594	659	892	989	130	200	411
78	594	892	659	130	989	411	200
79	659	989	594	200	892	411	130
80	659	594	989	892	200	130	411
81	892	130	594	411	659	200	989
82	892	594	130	659	411	989	200
83	200	989	411	659	130	594	892
84	200	411	989	130	659	892	594

Replication 1, 2, & 3 (Mix):

Distribution Order / Panelist	1st	2nd	3rd	4th	5th	6th	7th
85 (1)	130	594	200	989	892	411	659
86 (2)	130	200	594	892	989	659	411
87 (3)	989	411	594	659	130	892	200
88 (1)	989	594	411	130	659	200	892
89 (2)	411	989	659	594	892	130	200
90 (3)	411	659	989	892	594	200	130
91 (1)	594	130	989	200	411	892	659
92 (2)	594	989	130	411	200	659	892
93 (3)	659	411	892	989	200	594	130
94 (1)	659	892	411	200	989	130	594
95 (2)	892	659	200	411	130	989	594
96 (3)	892	200	659	130	411	594	989
97 (1)	200	130	892	594	659	989	411
98 (2)	200	892	130	659	594	411	989

Appendix F – Mixed-Model ANOVA and Pearson Correlation Data for Descriptive Analysis

Sheen Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	24.806	4.1344	6	12	1.1169	0.4081	

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **Shn ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1056.9	2141.8				
(1|Rep)	13	-1056.9	2139.8	0.074	1	0.7861407	
(1|Panelist)	13	-1077.5	2181.0	41.234	1	1.351e-10	***
(1|Sample:Panelist)	13	-1056.9	2139.8	0.000	1	0.9999442	
(1|Sample:Rep)	13	-1066.8	2159.7	19.919	1	8.080e-06	***
(1|Panelist:Rep)	13	-1061.2	2148.5	8.721	1	0.0031451	**
(1|Sample:Panelist:Rep)	13	-1062.3	2150.7	10.926	1	0.0009483	***

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Sheen Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYC	5.06	1.25	16.9	1.26	8.85	a
FYC	5.40	1.25	16.9	1.60	9.20	a
FYA	5.50	1.25	16.9	1.70	9.30	a
FYB	5.79	1.25	16.9	1.99	9.59	a
GFYA	6.38	1.25	16.9	2.58	10.18	a
CTRL	6.55	1.25	16.9	2.75	10.35	a
GFYB	6.92	1.25	16.9	3.12	10.72	a

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Gooeyness Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	349.22	58.203	6	15.61	7.5369	0.0006323	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **GOOY ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1175.2	2378.4				
(1|Rep)	13	-1175.2	2376.4	0.0000	1	1.000000	
(1|Panelist)	13	-1179.3	2384.6	8.1625	1	0.004277	**
(1|Sample:Panelist)	13	-1176.0	2378.1	1.6029	1	0.205490	
(1|Sample:Rep)	13	-1177.3	2380.6	4.1924	1	0.040605	*
(1|Panelist:Rep)	13	-1183.0	2392.0	15.5626	1	7.982e-05	***
(1|Sample:Panelist:Rep)	13	-1175.4	2376.8	0.3476	1	0.555497	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Gooeyness Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYB	4.40	0.75	20.1	2.16	6.63	a
FYC	4.63	0.75	20.1	2.39	6.86	a
GFYC	4.86	0.75	20.1	2.62	7.09	a
GFYA	5.82	0.75	20.1	3.58	8.06	a
FYB	5.98	0.75	20.1	3.74	8.21	a
FYA	6.88	0.75	20.1	4.64	9.12	ab
CTRL	8.80	0.75	20.1	6.57	11.04	b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Hardness Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	320.73	53.456	6	60	6.3075	3.492e-05	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **HRD ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1203.5	2434.9				
(1|Rep)	13	-1203.5	2432.9	0.0000	1	0.999905	
(1|Panelist)	13	-1207.4	2440.8	7.8604	1	0.005053	**
(1|Sample:Panelist)	13	-1204.1	2434.1	1.1819	1	0.276966	
(1|Sample:Rep)	13	-1203.5	2432.9	0.0000	1	0.999969	
(1|Panelist:Rep)	13	-1215.5	2457.0	24.0156	1	9.556e-07	***
(1|Sample:Panelist:Rep)	13	-1204.2	2434.4	1.4498	1	0.228553	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Hardness Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
CTRL	4.40	0.75	20.1	2.16	6.63	a
FYA	4.63	0.75	20.1	2.39	6.86	a
FYB	4.86	0.75	20.1	2.62	7.09	a
GFYA	5.82	0.75	20.1	3.58	8.06	a
FYC	5.98	0.75	20.1	3.74	8.21	a
GFYB	6.88	0.75	20.1	4.64	9.12	ab
GFYC	8.80	0.75	20.1	6.57	11.04	b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Rate of Melt Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	54.202	9.0336	6	13.934	1.23	0.3488	

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **MoR ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1158.7	2345.4				
(1|Rep)	13	-1158.7	2343.4	0.000	1	1.0000	
(1|Panelist)	13	-1183.4	2392.7	49.337	1	2.156e-12	***
(1|Sample:Panelist)	13	-1158.7	2343.4	0.000	1	1.0000	
(1|Sample:Rep)	13	-1158.9	2343.7	0.312	1	0.5766	
(1|Panelist:Rep)	13	-1158.7	2343.4	0.008	1	0.9271	
(1|Sample:Panelist:Rep)	13	-1159.8	2345.6	2.227	1	0.1356	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Rate of Melt Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
CTRL	5.98	1.06	13	2.60	9.35	a
FYB	6.41	1.06	13	3.03	9.78	a
FYA	6.61	1.06	13	3.24	9.99	a
GFYB	6.78	1.06	13	3.41	10.16	a
GFYA	7.11	1.06	13	3.74	10.49	a
GFYC	7.17	1.06	13	3.79	10.54	a
FYC	7.21	1.06	13	3.84	10.59	a

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Creaminess Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	112.27	18.711	6	13.646	5.2683	0.005264	**

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **CRM ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1052.8	2133.6				
(1|Rep)	13	-1052.8	2131.6	0.0626	1	0.802390	
(1|Panelist)	13	-1058.0	2142.0	10.4181	1	0.001248	**
(1|Sample:Panelist)	13	-1053.7	2133.3	1.7716	1	0.183190	
(1|Sample:Rep)	13	-1061.3	2148.5	16.9786	1	3.78e-05	***
(1|Panelist:Rep)	13	-1063.8	2153.5	21.9418	1	2.81e-06	***
(1|Sample:Panelist:Rep)	13	-1057.8	2141.5	9.9779	1	0.001584	**

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Creaminess Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYB	7.93	0.835	20.4	5.44	10.4	a
FYC	8.73	0.835	20.4	6.25	11.2	ab
GFYC	8.90	0.835	20.4	6.41	11.4	ab
FYB	10.52	0.835	20.4	8.03	13.0	ab
GFYA	10.75	0.835	20.4	8.26	13.2	ab
FYA	11.32	0.835	20.4	8.83	13.8	b
CTRL	11.77	0.835	20.4	9.29	14.3	b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Denseness Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	17.922	2.987	6	19.532	0.5199	0.7863	

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **DNS ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1141.7	2311.4				
(1|Rep)	13	-1141.7	2309.4	0.0000	1	1.00000	
(1|Panelist)	13	-1151.0	2328.1	18.6420	1	1.577e-05	***
(1|Sample:Panelist)	13	-1144.3	2314.5	5.0757	1	0.02426	*
(1|Sample:Rep)	13	-1143.9	2313.9	4.4169	1	0.03558	*
(1|Panelist:Rep)	13	-1144.7	2315.3	5.8642	1	0.01545	*
(1|Sample:Panelist:Rep)	13	-1144.3	2314.7	5.2494	1	0.02195	*

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Denseness Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYB	8.56	0.841	23	6.09	11.0	a
FYC	8.94	0.841	23	6.47	11.4	a
CTRL	9.30	0.841	23	6.83	11.8	a
FYB	9.50	0.841	23	7.02	12.0	a
GFYC	9.63	0.841	23	7.15	12.1	a
GFYA	9.65	0.841	23	7.18	12.1	a
FYA	9.69	0.841	23	7.22	12.2	a

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Iciness Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	82.323	13.72	6	13.752	2.6475	0.0635	

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **ICI ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1114.9	2257.8				
(1|Rep)	13	-1115.5	2257.0	1.1940	1	0.274525	
(1|Panelist)	13	-1118.5	2263.0	7.2191	1	0.007213	**
(1|Sample:Panelist)	13	-1115.5	2256.9	1.1217	1	0.289550	
(1|Sample:Rep)	13	-1117.8	2261.5	5.7045	1	0.016921	*
(1|Panelist:Rep)	13	-1118.7	2263.4	7.5892	1	0.005872	**
(1|Sample:Panelist:Rep)	13	-1118.2	2262.5	6.7098	1	0.009588	**

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Iciness Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
CTRL	2.67	0.765	14.3	0.277	5.06	a
GFYA	2.80	0.765	14.3	0.415	5.19	a
FYA	2.82	0.765	14.3	0.433	5.21	a
FYB	3.02	0.765	14.3	0.628	5.41	a
GFYC	3.52	0.765	14.3	1.128	5.91	a
FYC	4.27	0.765	14.3	1.878	6.66	a
GFYB	5.13	0.765	14.3	2.742	7.52	a

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Smoothness Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	102.57	17.095	6	14.876	4.5262	0.008342	**

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **SMTH ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1095.2	2218.4				
(1|Rep)	13	-1095.3	2216.7	0.2371	1	0.626321	
(1|Panelist)	13	-1100.3	2226.7	10.2488	1	0.001368	**
(1|Sample:Panelist)	13	-1096.6	2219.1	2.6736	1	0.102025	
(1|Sample:Rep)	13	-1099.6	2225.2	8.7605	1	0.003078	**
(1|Panelist:Rep)	13	-1100.7	2227.4	10.9600	1	0.000931	***
(1|Sample:Panelist:Rep)	13	-1108.6	2243.1	26.6638	1	2.421e-07	***

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Smoothness Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYB	6.27	0.865	20.5	3.69	8.84	a
FYC	7.87	0.865	20.5	5.30	10.45	ab
GFYC	8.35	0.865	20.5	5.78	10.93	ab
FYB	9.18	0.865	20.5	6.60	11.75	ab
GFYA	9.41	0.865	20.5	6.83	11.98	ab
FYA	9.54	0.865	20.5	6.97	12.12	b
CTRL	10.61	0.865	20.5	8.03	13.18	b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Gumminess Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	166.6	27.767	6	60	4.4008	0.0009496	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **GMY ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1142.3	2312.6				
(1|Rep)	13	-1143.5	2313.1	2.4268	1	0.11928	
(1|Panelist)	13	-1150.0	2326.1	15.4503	1	8.47e-05	***
(1|Sample:Panelist)	13	-1145.4	2316.9	6.2668	1	0.01230	*
(1|Sample:Rep)	13	-1142.3	2310.6	0.0000	1	1.00000	
(1|Panelist:Rep)	13	-1145.1	2316.2	5.5661	1	0.01831	*
(1|Sample:Panelist:Rep)	13	-1143.2	2312.4	1.7726	1	0.18306	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Gumminess Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
FYC	3.98	0.766	16.7	1.65	6.32	a
GFYC	4.80	0.766	16.7	2.47	7.14	a
GFYB	5.01	0.766	16.7	2.67	7.34	ab
FYB	5.26	0.766	16.7	2.92	7.60	ab
FYA	5.63	0.766	16.7	3.29	7.96	ab
GFYA	5.85	0.766	16.7	3.51	8.18	ab
CTRL	6.98	0.766	16.7	4.65	9.32	b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Mouth Coating Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	139.39	23.232	6	60	4.2025	0.001359	**

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **MtCt ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1146.5	2321.0				
(1|Rep)	13	-1148.1	2322.2	3.1840	1	0.074361	.
(1|Panelist)	13	-1151.5	2329.1	10.0921	1	0.001489	**
(1|Sample:Panelist)	13	-1147.3	2320.6	1.5817	1	0.208511	
(1|Sample:Rep)	13	-1146.5	2319.0	0.0000	1	0.999940	
(1|Panelist:Rep)	13	-1155.2	2336.4	17.4433	1	2.96e-05	***
(1|Sample:Panelist:Rep)	13	-1152.6	2331.2	12.2074	1	0.000476	***

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Mouth Coating Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
FYC	6.89	0.893	9.31	3.84	9.94	a
GFYC	7.68	0.893	9.31	4.63	10.73	ab
GFYB	8.06	0.893	9.31	5.01	11.11	ab
FYB	8.30	0.893	9.31	5.25	11.35	ab
FYA	8.61	0.893	9.31	5.56	11.66	ab
GFYA	9.02	0.893	9.31	5.97	12.07	b
CTRL	9.59	0.893	9.31	6.54	12.64	b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Sour Flavor Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	377.2	62.867	6	25.894	13.032	9.285e-07	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **SourFlv ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1112.1	2252.2				
(1|Rep)	13	-1112.6	2251.3	1.0469	1	0.306215	
(1|Panelist)	13	-1122.8	2271.5	21.2871	1	3.954e-06	***
(1|Sample:Panelist)	13	-1121.6	2269.2	19.0177	1	1.295e-05	***
(1|Sample:Rep)	13	-1115.0	2256.0	5.8163	1	0.015879	*
(1|Panelist:Rep)	13	-1119.0	2264.1	13.8217	1	0.000201	***
(1|Sample:Panelist:Rep)	13	-1113.4	2252.7	2.5097	1	0.113147	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Sour Flavor Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
CTRL	1.87	0.994	21.1	-1.086	4.82	a
FYA	2.66	0.994	21.1	-0.295	5.61	a
FYB	3.10	0.994	21.1	0.150	6.05	ab
GFYA	3.35	0.994	21.1	0.398	6.30	ab
FYC	3.78	0.994	21.1	0.833	6.74	ab
GFYB	5.73	0.994	21.1	2.779	8.68	bc
GFYC	8.38	0.994	21.1	5.429	11.33	c

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Fat Flavor Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	250.42	41.737	6	60	7.2305	7.779e-06	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **FatFlv ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1117.9	2263.8				
(1|Rep)	13	-1121.1	2268.3	6.4369	1	0.01118	*
(1|Panelist)	13	-1131.1	2288.1	26.2817	1	2.951e-07	***
(1|Sample:Panelist)	13	-1119.0	2263.9	2.1037	1	0.14694	
(1|Sample:Rep)	13	-1117.9	2261.8	0.0000	1	0.99959	
(1|Panelist:Rep)	13	-1120.1	2266.2	4.3867	1	0.03622	*
(1|Sample:Panelist:Rep)	13	-1118.8	2263.6	1.7612	1	0.18447	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Fat Flavor Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYC	6.75	0.906	13	3.87	9.63	a
FYC	7.79	0.906	13	4.91	10.67	ab
FYB	8.34	0.906	13	5.46	11.22	abc
GFYB	8.34	0.906	13	5.47	11.22	abc
GFYA	9.05	0.906	13	6.17	11.92	bc
FYA	9.26	0.906	13	6.38	12.14	bc
CTRL	9.86	0.906	13	6.99	12.74	c

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Bitterness Flavor Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	5.0391	0.83985	6	13.871	1.4937	0.251	

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **BitFlv ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-615.66	1259.3				
(1|Rep)	13	-616.52	1259.0	1.7349	1	0.1877924	
(1|Panelist)	13	-628.11	1282.2	24.9141	1	5.994e-07	***
(1|Sample:Panelist)	13	-616.28	1258.6	1.2439	1	0.2647186	
(1|Sample:Rep)	13	-615.68	1257.4	0.0431	1	0.8355977	
(1|Panelist:Rep)	13	-615.66	1257.3	0.0088	1	0.9252249	
(1|Sample:Panelist:Rep)	13	-622.18	1270.4	13.0509	1	0.0003031	***

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Bitterness Flavor Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
FYA	0.611	0.242	19.1	-0.1153	1.34	a
FYC	0.673	0.242	19.1	-0.0531	1.40	a
GFYA	0.733	0.242	19.1	0.0067	1.46	a
FYB	0.762	0.242	19.1	0.0355	1.49	a
GFYB	0.820	0.242	19.1	0.0931	1.55	a
CTRL	0.825	0.242	19.1	0.0984	1.55	a
GFYC	1.153	0.242	19.1	0.4264	1.88	a

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Alkaline Flavor Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	18.01	3.0016	6	60.04	1.0315	0.414	

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **AlkFlv ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1003.8	2035.5				
(1|Rep)	13	-1003.8	2033.5	0.0142	1	0.90517	
(1|Panelist)	13	-1011.4	2048.9	15.3646	1	8.863e-05	***
(1|Sample:Panelist)	13	-1003.8	2033.5	0.0149	1	0.90272	
(1|Sample:Rep)	13	-1003.8	2033.5	0.0000	1	1.00000	
(1|Panelist:Rep)	13	-1006.1	2038.2	4.7117	1	0.02996	*
(1|Sample:Panelist:Rep)	13	-1014.6	2055.2	21.6671	1	3.243e-06	***

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Alkaline Flavor Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
FYA	1.11	0.521	15.8	-0.4911	2.72	a
GFYB	1.45	0.521	15.8	-0.1494	3.06	a
GFYA	1.47	0.521	15.8	-0.1358	3.07	a
FYB	1.47	0.521	15.8	-0.1343	3.07	a
CTRL	1.58	0.521	15.8	-0.0267	3.18	a
FYC	1.67	0.521	15.8	0.0657	3.27	a
GFYC	2.13	0.521	15.8	0.5271	3.74	a

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Sweet Flavor Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	206.03	34.339	6	60	15.755	9.133e-11	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **SwtFlv ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-934.08	1896.2				
(1|Rep)	13	-935.18	1896.3	2.1866	1	0.139214	
(1|Panelist)	13	-942.05	1910.1	15.9286	1	6.578e-05	***
(1|Sample:Panelist)	13	-936.91	1899.8	5.6574	1	0.017382	*
(1|Sample:Rep)	13	-934.08	1894.2	0.0000	1	1.000000	
(1|Panelist:Rep)	13	-946.74	1919.5	25.3046	1	4.895e-07	***
(1|Sample:Panelist:Rep)	13	-937.72	1901.5	7.2789	1	0.006977	**

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Sweet Flavor Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYC	8.01	0.646	12.9	5.96	10.1	a
GFYB	8.94	0.646	12.9	6.88	11.0	ab
FYC	9.00	0.646	12.9	6.94	11.1	abc
FYB	9.93	0.646	12.9	7.87	12.0	bcd
GFYA	10.32	0.646	12.9	8.27	12.4	cde
FYA	10.61	0.646	12.9	8.56	12.7	de
CTRL	11.33	0.646	12.9	9.27	13.4	e

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Milk Flavor Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	129.78	21.63	6	60	7.0517	1.035e-05	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **MlkFlv ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1005.5	2038.9				
(1|Rep)	13	-1006.2	2038.5	1.518	1	0.2179725	
(1|Panelist)	13	-1024.5	2075.0	38.061	1	6.857e-10	***
(1|Sample:Panelist)	13	-1011.1	2048.2	11.252	1	0.0007956	***
(1|Sample:Rep)	13	-1005.5	2036.9	0.000	1	1.0000000	
(1|Panelist:Rep)	13	-1007.5	2041.1	4.178	1	0.0409627	*
(1|Sample:Panelist:Rep)	13	-1008.2	2042.5	5.516	1	0.0188408	*

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Milk Flavor Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYC	8.37	0.852	15.1	5.73	11.0	a
GFYB	9.37	0.852	15.1	6.73	12.0	ab
FYC	9.85	0.852	15.1	7.21	12.5	abc
FYB	10.59	0.852	15.1	7.95	13.2	bc
FYA	10.66	0.852	15.1	8.02	13.3	bc
GFYA	10.87	0.852	15.1	8.23	13.5	bc
CTRL	11.12	0.852	15.1	8.48	13.8	c

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Sour Aftertaste Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	283.42	47.236	6	22.059	9.5256	3.272e-05	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **SourAft ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1099.7	2227.5				
(1|Rep)	13	-1100.0	2226.0	0.5067	1	0.4765688	
(1|Panelist)	13	-1102.3	2230.6	5.0758	1	0.0242615	*
(1|Sample:Panelist)	13	-1106.0	2238.0	12.5488	1	0.0003965	***
(1|Sample:Rep)	13	-1102.6	2231.3	5.8021	1	0.0160068	*
(1|Panelist:Rep)	13	-1105.8	2237.7	12.2199	1	0.0004728	***
(1|Sample:Panelist:Rep)	13	-1100.5	2227.0	1.4947	1	0.2214908	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' '; 1**							

Sour Aftertaste Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
CTRL	0.99	0.716	21.2	-1.135	3.12	a
FYA	1.34	0.716	21.2	-0.786	3.46	a
FYB	1.85	0.716	21.2	-0.280	3.97	a
FYC	2.38	0.716	21.2	0.258	4.51	a
GFYA	2.41	0.716	21.2	0.280	4.53	a
GFYB	3.48	0.716	21.2	1.356	5.61	a
GFYC	6.26	0.716	21.2	4.133	8.38	b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Fat Aftertaste Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	220.98	36.83	6	60	6.3243	3.396e-05	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **FatAft ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1119.1	2266.1				
(1|Rep)	13	-1124.0	2274.1	9.979	1	0.001584	**
(1|Panelist)	13	-1137.2	2300.4	36.291	1	1.7e-09	***
(1|Sample:Panelist)	13	-1120.0	2266.0	1.880	1	0.170281	
(1|Sample:Rep)	13	-1119.1	2264.1	0.000	1	1.000000	
(1|Panelist:Rep)	13	-1122.9	2271.7	7.618	1	0.005780	**
(1|Sample:Panelist:Rep)	13	-1119.5	2265.0	0.884	1	0.347164	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Fat Aftertaste Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYC	5.27	1.21	12.2	1.37	9.17	a
FYC	5.90	1.21	12.2	2.00	9.80	ab
FYB	6.45	1.21	12.2	2.55	10.35	abc
GFYB	6.90	1.21	12.2	3.00	10.80	abc
FYA	7.33	1.21	12.2	3.42	11.23	bc
GFYA	7.50	1.21	12.2	3.60	11.40	bc
CTRL	7.88	1.21	12.2	3.98	11.78	c

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Bitter Aftertaste Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	3.8036	0.63393	6	60	0.9639	0.4574	

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **BitAft ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-680.36	1388.7				
(1|Rep)	13	-680.71	1387.4	0.702	1	0.4022	
(1|Panelist)	13	-690.45	1406.9	20.168	1	7.093e-06	***
(1|Sample:Panelist)	13	-680.60	1387.2	0.472	1	0.4921	
(1|Sample:Rep)	13	-680.36	1386.7	0.000	1	0.9999	
(1|Panelist:Rep)	13	-680.36	1386.7	0.000	1	1.0000	
(1|Sample:Panelist:Rep)	13	-697.80	1421.6	34.870	1	3.525e-09	***

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Bitter Aftertaste Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
FYA	0.657	0.248	19.9	-0.0840	1.40	a
GFYA	0.661	0.248	19.9	-0.0802	1.40	a
FYB	0.667	0.248	19.9	-0.0734	1.41	a
CTRL	0.693	0.248	19.9	-0.0476	1.43	a
GFYB	0.964	0.248	19.9	0.2236	1.71	a
FYC	0.974	0.248	19.9	0.2335	1.72	a
GFYC	0.987	0.248	19.9	0.2463	1.73	a

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Alkaline Aftertaste Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	12.448	2.0746	6	192	0.574	0.7507	

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **AlkAft ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1008.3	2044.5				
(1|Rep)	13	-1008.3	2042.5	0.0000	1	0.9999486	
(1|Panelist)	13	-1015.4	2056.9	14.3644	1	0.0001506	***
(1|Sample:Panelist)	13	-1008.3	2042.5	0.0000	1	0.9998639	
(1|Sample:Rep)	13	-1008.3	2042.5	0.0000	1	1.0000000	
(1|Panelist:Rep)	13	-1012.5	2051.1	8.5543	1	0.0034471	**
(1|Sample:Panelist:Rep)	13	-1010.4	2046.8	4.2305	1	0.0397047	*

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Alkaline Aftertaste Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
FYA	1.40	0.485	14.8	-0.110	2.91	a
FYB	1.65	0.485	14.8	0.140	3.16	a
GFYA	1.65	0.485	14.8	0.143	3.16	a
CTRL	1.71	0.485	14.8	0.200	3.22	a
GFYB	1.80	0.485	14.8	0.287	3.30	a
GFYC	1.94	0.485	14.8	0.431	3.45	a
FYC	2.01	0.485	14.8	0.505	3.52	a

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Sweet Aftertaste Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	168.09	28.014	6	22.686	7.5455	0.000156	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **SwtAft ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1029.7	2087.4				
(1|Rep)	13	-1031.8	2089.6	4.236	1	0.0395747	*
(1|Panelist)	13	-1041.3	2108.5	23.153	1	1.496e-06	***
(1|Sample:Panelist)	13	-1035.7	2097.4	12.008	1	0.0005298	***
(1|Sample:Rep)	13	-1031.8	2089.6	4.243	1	0.0394129	*
(1|Panelist:Rep)	13	-1050.6	2127.1	41.784	1	1.019e-10	***
(1|Sample:Panelist:Rep)	13	-1029.7	2085.4	0.000	1	0.9999192	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Sweet Aftertaste Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYC	6.04	1.06	12.5	2.66	9.43	a
GFYB	7.22	1.06	12.5	3.84	10.61	ab
FYC	7.25	1.06	12.5	3.87	10.63	ab
FYB	8.24	1.06	12.5	4.86	11.63	bc
GFYA	8.48	1.06	12.5	5.10	11.87	bc
FYA	8.66	1.06	12.5	5.27	12.04	bc
CTRL	9.63	1.06	12.5	6.24	13.01	c

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Milk Aftertaste Mixed-Model ANOVA:

Type III Analysis of Variance Table with Satterthwaite's method							
	Sum Sq	Mean Sq	Num DF	Den DF	F Value	Pr (>F)	
Sample	164.19	27.365	6	25.428	6.2557	0.0003899	***

ANOVA Table for Random-Effects: Single Term Deletions							
Model: **MlkAft ~ Sample + (1 | Rep) + (1 | Panelist) + (1 | Sample:Panelist) + (1 | Sample:Rep) + (1 | Panelist:Rep) + (1 | Sample:Panelist:Rep)**							
	npar	**logLik**	**AIC**	**LRT**	**Df**	**Pr(>Chisq)**	**Sig.**
<none>	14	-1059.7	2147.4				
(1|Rep)	13	-1060.7	2147.4	1.964	1	0.161099	
(1|Panelist)	13	-1078.3	2182.6	37.167	1	1.084e-09	***
(1|Sample:Panelist)	13	-1065.1	2156.2	10.758	1	0.001038	**
(1|Sample:Rep)	13	-1059.7	2145.5	0.003	1	0.956172	
(1|Panelist:Rep)	13	-1064.3	2154.6	9.176	1	0.002452	**
(1|Sample:Panelist:Rep)	13	-1059.9	2145.7	0.286	1	0.593096	

Signif. codes: 0 '*' ; 0.001 '**' ; 0.01 '*' ; 0.05 '.' ; 0.1 ' ' ; 1**							

Milk Aftertaste Descriptive Statistics:

Sample	lsmean	SE	df	lower.CL	upper.CL	.group
GFYC	7.00	0.988	14.4	3.92	10.1	a
GFYB	7.91	0.988	14.4	4.83	11.0	ab
FYC	8.14	0.988	14.4	5.05	11.2	abc
GFYA	8.93	0.988	14.4	5.84	12.0	bc
FYB	9.31	0.988	14.4	6.22	12.4	bc
FYA	9.34	0.988	14.4	6.25	12.4	bc
CTRL	9.66	0.988	14.4	6.57	12.7	c

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05

Flattened correlation matrix of descriptive data containing the correlation coefficient values (Pearson method) of the appearance, scoopability, texture, flavor, and aftertaste attributes among seven frozen dessert samples.

Variable A	Variable B	Correlation Coefficient	P-Value
Sheen	Iciness	0.3251054176	7.81E-13
Sheen	Gooeyness	0.2254520293	9.78E-07
Iciness	Gooeyness	-0.1074713745	0.020863
Sheen	Hardness	0.0960883503	0.038968
Iciness	Hardness	0.1801588917	9.87E-05
Gooeyness	Hardness	-0.3545263360	4E-15
Sheen	Melt Of Rate	-0.0257111606	0.581473
Iciness	Melt Of Rate	-0.0575613380	0.216865
Gooeyness	Melt Of Rate	-0.0667913241	0.151762
Hardness	Melt Of Rate	0.2924379404	1.46E-10
Sheen	Creaminess	-0.0383373932	0.411019
Iciness	Creaminess	-0.3606049671	1.33E-15
Gooeyness	Creaminess	0.2013896935	1.29E-05
Hardness	Creaminess	-0.2534642186	3.32E-08
Melt Of Rate	Creaminess	-0.0516235222	0.268148
Sheen	Denseness	-0.1167776130	0.01201
Iciness	Denseness	-0.1738953540	0.000172
Gooeyness	Denseness	-0.1972734310	1.95E-05
Hardness	Denseness	0.1603639098	0.00054
Melt Of Rate	Denseness	-0.0446659001	0.338096
Creaminess	Denseness	0.4189366813	0
Sheen	Smoothness	-0.0337713906	0.468987
Iciness	Smoothness	-0.3629006478	8.88E-16
Gooeyness	Smoothness	0.2772583957	1.34E-09
Hardness	Smoothness	-0.0605856540	0.193633
Melt Of Rate	Smoothness	0.1265760813	0.006445
Creaminess	Smoothness	0.6280199828	0
Denseness	Smoothness	0.2608927998	1.26E-08
Sheen	Gumminess	0.1621876935	0.000466
Iciness	Gumminess	-0.1570326738	0.000706
Gooeyness	Gumminess	0.2802863648	8.7E-10
Hardness	Gumminess	-0.0009957278	0.982971
Melt Of Rate	Gumminess	0.0428455657	0.35817
Creaminess	Gumminess	0.0826683101	0.075879

Denseness	Gumminess	0.0014214217	0.975693
Smoothness	Gumminess	0.1974506769	1.91E-05
Sheen	Mouth Coating	0.1400490905	0.002553
Iciness	Mouth Coating	-0.2800183564	9.04E-10
Gooeyness	Mouth Coating	0.0914359926	0.049515
Hardness	Mouth Coating	0.0199156839	0.669413
Melt Of Rate	Mouth Coating	0.0693750292	0.13651
Creaminess	Mouth Coating	0.3489647517	1.11E-14
Denseness	Mouth Coating	0.0950627231	0.041113
Smoothness	Mouth Coating	0.3504885932	8.44E-15
Gumminess	Mouth Coating	0.4248513827	0
Sheen	Sour Flavor	0.1149060691	0.013462
Iciness	Sour Flavor	0.0685378994	0.141317
Gooeyness	Sour Flavor	-0.1270011357	0.006267
Hardness	Sour Flavor	0.2360721370	2.85E-07
Melt Of Rate	Sour Flavor	0.2411931706	1.54E-07
Creaminess	Sour Flavor	-0.0790551547	0.089644
Denseness	Sour Flavor	0.1291515155	0.005434
Smoothness	Sour Flavor	0.0159724968	0.732044
Gumminess	Sour Flavor	0.0196818582	0.673069
Mouth Coating	Sour Flavor	0.1463268317	0.001612
Sheen	Fat Flavor	-0.0245816141	0.598187
Iciness	Fat Flavor	-0.1645437288	0.000383
Gooeyness	Fat Flavor	0.1427226521	0.002104
Hardness	Fat Flavor	-0.0947469498	0.041793
Melt Of Rate	Fat Flavor	0.0132188950	0.776892
Creaminess	Fat Flavor	0.5335690419	0
Denseness	Fat Flavor	0.2924176378	1.47E-10
Smoothness	Fat Flavor	0.4958393884	0
Gumminess	Fat Flavor	0.1075535770	0.020765
Mouth Coating	Fat Flavor	0.3893747409	0
Sour Flavor	Fat Flavor	0.0711906889	0.126518
Sheen	Bitter Flavor	0.0840274691	0.071168
Iciness	Bitter Flavor	0.1443337229	0.001869
Gooeyness	Bitter Flavor	-0.0345439061	0.458874
Hardness	Bitter Flavor	0.1247343092	0.007268
Melt Of Rate	Bitter Flavor	-0.0377992730	0.417622
Creaminess	Bitter Flavor	-0.2252597267	1E-06
Denseness	Bitter Flavor	-0.0703822266	0.130894
Smoothness	Bitter Flavor	-0.1222777155	0.008513

Gumminess	Bitter Flavor	0.1107554464	0.017243
Mouth Coating	Bitter Flavor	0.0122449271	0.792943
Sour Flavor	Bitter Flavor	0.1780551360	0.000119
Fat Flavor	Bitter Flavor	-0.0900695248	0.053032
Sheen	Alkaline Flavor	-0.0256517446	0.582347
Iciness	Alkaline Flavor	0.0875707734	0.060002
Gooeyness	Alkaline Flavor	-0.2046258582	9.28E-06
Hardness	Alkaline Flavor	-0.0090207093	0.846668
Melt Of Rate	Alkaline Flavor	-0.0909892910	0.050642
Creaminess	Alkaline Flavor	0.0826610979	0.075905
Denseness	Alkaline Flavor	0.1915052353	3.42E-05
Smoothness	Alkaline Flavor	-0.0367511677	0.43066
Gumminess	Alkaline Flavor	-0.1509497787	0.001136
Mouth Coating	Alkaline Flavor	-0.0083116971	0.858588
Sour Flavor	Alkaline Flavor	0.2093165633	5.7E-06
Fat Flavor	Alkaline Flavor	0.0691361432	0.137869
Bitter Flavor	Alkaline Flavor	0.3319278273	2.41E-13
Sheen	Sweet Flavor	-0.2126956745	3.98E-06
Iciness	Sweet Flavor	-0.3189462775	2.2E-12
Gooeyness	Sweet Flavor	0.0958141624	0.039532
Hardness	Sweet Flavor	-0.2168717675	2.54E-06
Melt Of Rate	Sweet Flavor	-0.0019378527	0.966866
Creaminess	Sweet Flavor	0.5686946621	0
Denseness	Sweet Flavor	0.2562805451	2.31E-08
Smoothness	Sweet Flavor	0.4608871393	0
Gumminess	Sweet Flavor	0.0406869730	0.382922
Mouth Coating	Sweet Flavor	0.2774007986	1.31E-09
Sour Flavor	Sweet Flavor	-0.1823482614	8.08E-05
Fat Flavor	Sweet Flavor	0.6043820257	0
Bitter Flavor	Sweet Flavor	-0.2300206718	5.8E-07
Alkaline Flavor	Sweet Flavor	0.0007313615	0.987492
Sheen	Milk Flavor	-0.1717783543	0.000207
Iciness	Milk Flavor	-0.2254142515	9.83E-07
Gooeyness	Milk Flavor	0.0490207294	0.293057
Hardness	Milk Flavor	-0.1687455530	0.000269
Melt Of Rate	Milk Flavor	0.0605466475	0.193921
Creaminess	Milk Flavor	0.5348034680	0
Denseness	Milk Flavor	0.3055123959	1.95E-11
Smoothness	Milk Flavor	0.3956914575	0
Gumminess	Milk Flavor	0.0404588864	0.385597

Mouth Coating	Milk Flavor	0.2701465215	3.61E-09
Sour Flavor	Milk Flavor	-0.0651985570	0.161788
Fat Flavor	Milk Flavor	0.6076204759	0
Bitter Flavor	Milk Flavor	-0.2181297786	2.21E-06
Alkaline Flavor	Milk Flavor	0.0994268197	0.03263
Sweet Flavor	Milk Flavor	0.6641138119	0
Sheen	Sour Aftertaste	-0.0168446692	0.718019
Iciness	Sour Aftertaste	0.0959438575	0.039264
Gooeyness	Sour Aftertaste	-0.1271796096	0.006194
Hardness	Sour Aftertaste	0.0679678347	0.144663
Melt Of Rate	Sour Aftertaste	-0.1048856400	0.024162
Creaminess	Sour Aftertaste	-0.1317561214	0.004558
Denseness	Sour Aftertaste	0.0275399933	0.554884
Smoothness	Sour Aftertaste	-0.1484139969	0.001378
Gumminess	Sour Aftertaste	-0.0880515217	0.058605
Mouth Coating	Sour Aftertaste	-0.0252388448	0.588435
Sour Flavor	Sour Aftertaste	0.6894142205	0
Fat Flavor	Sour Aftertaste	-0.0891854288	0.055417
Bitter Flavor	Sour Aftertaste	0.1548125029	0.000842
Alkaline Flavor	Sour Aftertaste	0.2023254781	1.17E-05
Sweet Flavor	Sour Aftertaste	-0.2504978947	4.85E-08
Milk Flavor	Sour Aftertaste	-0.2031563383	1.08E-05
Sheen	Fat Aftertaste	-0.1472377864	0.001506
Iciness	Fat Aftertaste	-0.0639343454	0.170095
Gooeyness	Fat Aftertaste	-0.0142271110	0.760376
Hardness	Fat Aftertaste	-0.1929169361	2.98E-05
Melt Of Rate	Fat Aftertaste	-0.2790870616	1.03E-09
Creaminess	Fat Aftertaste	0.4332676413	0
Denseness	Fat Aftertaste	0.3244205434	8.77E-13
Smoothness	Fat Aftertaste	0.2927227085	1.4E-10
Gumminess	Fat Aftertaste	-0.0775617100	0.095889
Mouth Coating	Fat Aftertaste	0.2125553649	4.04E-06
Sour Flavor	Fat Aftertaste	-0.0503411499	0.280233
Fat Flavor	Fat Aftertaste	0.7284389804	0
Bitter Flavor	Fat Aftertaste	0.0044338512	0.92428
Alkaline Flavor	Fat Aftertaste	0.1788129884	0.000111
Sweet Flavor	Fat Aftertaste	0.4631748147	0
Milk Flavor	Fat Aftertaste	0.4702244489	0
Sour Aftertaste	Fat Aftertaste	0.0221980211	0.63415
Sheen	Bitter Aftertaste	0.1597240323	0.000569

Iciness	Bitter Aftertaste	0.1377447729	0.003009
Gooeyness	Bitter Aftertaste	0.0141821459	0.76111
Hardness	Bitter Aftertaste	0.1118914727	0.016126
Melt Of Rate	Bitter Aftertaste	-0.0661808227	0.155548
Creaminess	Bitter Aftertaste	-0.1788343332	0.000111
Denseness	Bitter Aftertaste	-0.0665690665	0.153132
Smoothness	Bitter Aftertaste	-0.1650718373	0.000367
Gumminess	Bitter Aftertaste	0.1251771700	0.007062
Mouth Coating	Bitter Aftertaste	-0.0094467952	0.839522
Sour Flavor	Bitter Aftertaste	0.1599623954	0.000558
Fat Flavor	Bitter Aftertaste	-0.1003722668	0.031004
Bitter Flavor	Bitter Aftertaste	0.6129219389	0
Alkaline Flavor	Bitter Aftertaste	0.2531896096	3.44E-08
Sweet Flavor	Bitter Aftertaste	-0.2178495797	2.28E-06
Milk Flavor	Bitter Aftertaste	-0.1117197856	0.01629
Sour Aftertaste	Bitter Aftertaste	0.1346354376	0.003741
Fat Aftertaste	Bitter Aftertaste	-0.0628435923	0.177515
Sheen	Alkaline Aftertaste	-0.0688508151	0.139505
Iciness	Alkaline Aftertaste	0.0537378019	0.249011
Gooeyness	Alkaline Aftertaste	-0.1572790177	0.000692
Hardness	Alkaline Aftertaste	0.0086560077	0.852795
Melt Of Rate	Alkaline Aftertaste	-0.1615019296	0.000492
Creaminess	Alkaline Aftertaste	0.0341007389	0.46466
Denseness	Alkaline Aftertaste	0.1091193471	0.018972
Smoothness	Alkaline Aftertaste	-0.0644913622	0.166397
Gumminess	Alkaline Aftertaste	-0.0920979754	0.047882
Mouth Coating	Alkaline Aftertaste	0.0293717696	0.52886
Sour Flavor	Alkaline Aftertaste	0.1164197309	0.012277
Fat Flavor	Alkaline Aftertaste	0.0927871493	0.04623
Bitter Flavor	Alkaline Aftertaste	0.2717030504	2.92E-09
Alkaline Flavor	Alkaline Aftertaste	0.7317231153	0
Sweet Flavor	Alkaline Aftertaste	0.0155493060	0.738882
Milk Flavor	Alkaline Aftertaste	0.0487848188	0.295389
Sour Aftertaste	Alkaline Aftertaste	0.1128483028	0.015234
Fat Aftertaste	Alkaline Aftertaste	0.1662105452	0.000333
Bitter Aftertaste	Alkaline Aftertaste	0.2958700333	8.69E-11
Sheen	Sweet Aftertaste	-0.1453465167	0.001734
Iciness	Sweet Aftertaste	-0.1537378295	0.000916
Gooeyness	Sweet Aftertaste	-0.0077466351	0.868111
Hardness	Sweet Aftertaste	-0.3093739961	1.05E-11

Melt Of Rate	Sweet Aftertaste	-0.2875691255	3.02E-10
Creaminess	Sweet Aftertaste	0.4239543025	0
Denseness	Sweet Aftertaste	0.2900886264	2.08E-10
Smoothness	Sweet Aftertaste	0.2172755002	2.43E-06
Gumminess	Sweet Aftertaste	-0.1445958901	0.001834
Mouth Coating	Sweet Aftertaste	-0.0159000203	0.733214
Sour Flavor	Sweet Aftertaste	-0.1354208132	0.003542
Fat Flavor	Sweet Aftertaste	0.4600784561	0
Bitter Flavor	Sweet Aftertaste	-0.1377857014	0.003
Alkaline Flavor	Sweet Aftertaste	0.0957956292	0.03957
Sweet Flavor	Sweet Aftertaste	0.5283271231	0
Milk Flavor	Sweet Aftertaste	0.3893022175	0
Sour Aftertaste	Sweet Aftertaste	0.0121877613	0.793887
Fat Aftertaste	Sweet Aftertaste	0.6700983866	0
Bitter Aftertaste	Sweet Aftertaste	-0.1962496799	2.16E-05
Alkaline Aftertaste	Sweet Aftertaste	0.0680012845	0.144465
Sheen	Milk Aftertaste	-0.2215348702	1.52E-06
Iciness	Milk Aftertaste	-0.1562678258	0.00075
Gooeyness	Milk Aftertaste	-0.0431359736	0.354918
Hardness	Milk Aftertaste	-0.2856735356	3.99E-10
Melt Of Rate	Milk Aftertaste	-0.1973160008	1.94E-05
Creaminess	Milk Aftertaste	0.4290014312	0
Denseness	Milk Aftertaste	0.2877601841	2.93E-10
Smoothness	Milk Aftertaste	0.2320760066	4.56E-07
Gumminess	Milk Aftertaste	-0.1455311266	0.001711
Mouth Coating	Milk Aftertaste	0.1047247788	0.024381
Sour Flavor	Milk Aftertaste	-0.0924318318	0.047076
Fat Flavor	Milk Aftertaste	0.5183258787	0
Bitter Flavor	Milk Aftertaste	-0.1038658827	0.025582
Alkaline Flavor	Milk Aftertaste	0.1481106312	0.00141
Sweet Flavor	Milk Aftertaste	0.4645641140	0
Milk Flavor	Milk Aftertaste	0.6582951917	0
Sour Aftertaste	Milk Aftertaste	-0.0541490817	0.245402
Fat Aftertaste	Milk Aftertaste	0.6677174249	0
Bitter Aftertaste	Milk Aftertaste	-0.1455639085	0.001707
Alkaline Aftertaste	Milk Aftertaste	0.0853268181	0.066891
Sweet Aftertaste	Milk Aftertaste	0.6946836116	0

Appendix G – Consumer Acceptance Consent & Ballot Information

INFORMED CONSENT FOR CONSUMER ACCEPTANCE TEST
By participating in this research project I consent to being a volunteer in the project, and I understand the following:

PROJECT BACKGROUND: This project involves gathering human sensory data on frozen desserts formulated with various types of yogurt. The data will be collected for analysis and may be published. You must be at least 18 years of age to participate.

PURPOSE: The purpose of this sensory test is to study the consumer perceived characteristics of frozen desserts formulated with various yogurts at different concentrations.

VOLUNTARY: This sensory test is entirely voluntary. You may refuse to answer any question or choose to withdraw from participation at any time without any penalty or loss of benefits to which you are otherwise entitled.

WHAT DO YOU DO? You will be asked to participate in a sensory panel.

BENEFITS: Frozen desserts can act as a vehicle to deliver essential nutrients, such as minerals and proteins, that are reduced during manufacturing. Your participation in this sensory test will allow us to better understand the flavor characteristics of frozen desserts that have been formulated with various yogurts that will improve the nutrient density of the product.
COMPENSATION: You will receive a voucher for 1 free scoop of ice cream from Buck's Ice Cream Parlor for completing this research study.
RISKS: The expected risks are none other than those encountered in normal daily food consumption. All product samples have been prepared under sanitary conditions in a health-department-inspected chocolate-production facility. Because the manufacturing facility uses milk, if you have a milk allergy, please do not participate in this study!

CONFIDENTIALITY: Your confidentiality will be maintained in that participation is anonymous. The data will only be reported in aggregate form. Thank you for your assistance in better understanding frozen desserts formulated with yogurt. Although great strides have been made in the instrumental analysis of foods, the development of new foods still requires the human sensory response and feedback.

Your efforts are greatly appreciated!!

If you have any questions regarding the study, please contact Dr. Ingolf Gruen at (573) 882-6746. If you have questions regarding your rights as a participant in research, please feel free to contact the Institutional Review Board at (573) 882-3181.

Study of Consumer Rating of Frozen Dessert Characteristics

Instructions

This is a sensory test about frozen desserts enhanced with various yogurts. There are three portions to this test. You will fill out our questionnaire. Then you will be tasting seven frozen desserts and evaluating them one after another. Finally, please rank the seven ice cream samples together.

Complete the following Questionnaire

1. Gender: Male □ Female □ Prefer not to answer □

2. What is your age group?
13-17 □ 18-30 □ 31-50 □ 51< □

3. How often do you consume frozen desserts?

□ Every day
□ A few times per week
□ A few times per month
□ A few times per year
□ Never

4. How often do you consume yogurt?

□ Every day
□ A few times per week
□ A few times per month
□ A few times per year
□ Never

5. Which type of frozen dessert do you prefer? Please Mark one!
□ Ice cream
□ Low – fat ice cream
□ Frozen Yogurt
□ Low – fat frozen yogurt

Thank you very much!

Instructions

1. Please masticate (eat) a piece of cracker than rinse your mouth with water before you start the test

2. Write the three-digit code of the frozen dessert sample, shown on the sample cup, on the line provided on each ballot.

3. Place the ice cream sample in your mouth and then rate how much you like or dislike the sample by placing a mark on the scale that best describes your opinion.

4. Consume another piece of cracker than rinse your mouth with water **before** you start the next sample

5. When you are done with your evaluation**, please flip the light switch** letting a lab assistant know you are ready for your next sample

6. Remember, **do not** re-taste the samples during the test.

7. Thank you for participating in the study!

If at any time you have a question about the test or directions, please ask the lab assistant.

Consumer Ballot for Frozen Dessert

Three-digit Sample Code: _____

How would you rate the **"OVERALL LIKING"** of this product?

Extremely dislike	Dislike very much	Dislike Moderately	Dislike Slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

How would you rate the **"OVERALL FLAVOR"** of this product?

Extremely dislike	Dislike very much	Dislike Moderately	Dislike Slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

How would you rate the **"OVERALL APPEARANCE"** of this product?

Extremely dislike	Dislike very much	Dislike Moderately	Dislike Slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

How would you rate the **"OVERALL TEXTURE"** of this product?

Extremely dislike	Dislike very much	Dislike Moderately	Dislike Slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

Please rank the seven ice cream samples in the order of preference.

TIES ARE NOT ALLOWED!

Sample #	Rank

Thank you again for participating in the study!

Appendix H – Consumer Preference Study Statistics & Panel Information

Panel Information Results

Gender:

	Frequency	Frequency (%)
Male	35	34.65
Female	66	65.35
Grand Total:	101	100

Age Group:

	Frequency	Frequency (%)
18-30	62	59.41
31-50	32	31.68
51<	9	8.91
Grand Total:	101	100

Frequency of Frozen Dessert Consumption:

	Frequency	Frequency (%)
Every day	1	0.99
Few times per week	34	33.663
Few times per month	56	55.446
Few times per year	10	9.901
Never	0	0
Grand Total:	101	100

Frequency of Yogurt Consumption:

	Frequency	Frequency (%)
Every day	9	8.911
Few times per week	23	22.772
Few times per month	40	39.604
Few times per year	25	24.752
Never	4	3.96
Grand Total:	101	100

Frozen Dessert Preference:

	Frequency	Frequency (%)
Ice cream	83	82.178
Low-fat ice cream	2	1.98
Frozen yogurt	14	13.861
Low-fat frozen yogurt	2	1.98
Grand Total:	101	100

Mixed-Model ANOVA of Degree of Overall Liking Scores

```
Type III Analysis of Variance Table with Satterthwaite's method
       Sum Sq Mean Sq NumDF DenDF F value   Pr(>F)
Sample 191.11  31.852     6  36.4   12.84 9.73e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
ANOVA-like table for random-effects: Single term deletions

Model:
DOL ~ Sample + (1 | Panel) + (1 | Sample:Panel)
                    npar  logLik    AIC    LRT Df Pr(>Chisq)
<none>                10 -1339.0 2697.9
(1 | Panel)            9 -1339.5 2696.9 0.9761  1    0.32315
(1 | Sample:Panel)     9 -1341.2 2700.4 4.4681  1    0.03453 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Degree of Overall Liking Descriptive Statistics:

```
 Sample lsmean    SE   df lower.CL upper.CL .group
 GFYC     5.63 0.209 39.4     5.04     6.22  a
 GFYB     5.64 0.209 39.5     5.05     6.23  a
 FYC      6.48 0.209 39.5     5.89     7.08  ab
 GFYA     6.81 0.209 39.5     6.22     7.40   bc
 FYB      7.10 0.209 39.5     6.51     7.69   bc
 FYA      7.11 0.209 39.5     6.51     7.70   bc
 CTRL     7.38 0.209 39.5     6.79     7.97    c

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05
```

Mixed-Model ANOVA of Degree of Overall Flavor Scores

```
Type III Analysis of Variance Table with Satterthwaite's method
       Sum Sq Mean Sq NumDF  DenDF F value    Pr(>F)
Sample 245.61  40.935     6 36.544  14.779 1.725e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
ANOVA-like table for random-effects: Single term deletions

Model:
DOF ~ Sample + (1 | Panel) + (1 | Sample:Panel)
                   npar  logLik    AIC    LRT Df Pr(>Chisq)
<none>               10 -1375.7 2771.3
(1 | Panel)           9 -1375.8 2769.7 0.3732  1    0.54129
(1 | Sample:Panel)    9 -1377.3 2772.6 3.3433  1    0.06748 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Degree of Overall Flavor Descriptive Statistics:

```
 Sample lsmean   SE   df lower.CL upper.CL .group
 GFYC     5.29 0.21 40.9     4.70     5.89  a
 GFYB     5.59 0.21 40.9     5.00     6.18  ab
 FYC      6.27 0.21 40.9     5.68     6.86   bc
 GFYA     6.77 0.21 40.9     6.18     7.36    cd
 FYB      6.92 0.21 40.9     6.33     7.51    cd
 FYA      6.96 0.21 40.9     6.37     7.55    cd
 CTRL     7.44 0.21 40.9     6.85     8.03     d

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05
```

Mixed-Model ANOVA of Degree of Overall Appearance Scores

```
Type III Analysis of Variance Table with Satterthwaite's method
       Sum Sq Mean Sq NumDF DenDF F value   Pr(>F)
Sample 44.554  7.4256     6 693.9  3.5659 0.001737 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
ANOVA-like table for random-effects: Single term deletions

Model:
DOA ~ Sample + (1 | Panel) + (1 | Sample:Panel)
                  npar  logLik    AIC    LRT Df Pr(>Chisq)
<none>              10 -1268.9 2557.8
(1 | Panel)          9 -1270.5 2559.0 3.1815  1    0.07448 .
(1 | Sample:Panel)   9 -1268.9 2555.8 0.0000  1    1.00000
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Degree of Overall Appearance Descriptive Statistics:

```
 Sample lsmean    SE   df lower.CL upper.CL .group
 GFYB     6.27 0.159 35.0     5.82     6.73  a
 GFYC     6.57 0.159 34.9     6.12     7.03  ab
 FYC      6.82 0.159 35.0     6.37     7.27  ab
 CTRL     6.83 0.159 35.0     6.38     7.28  ab
 FYB      6.91 0.159 35.0     6.46     7.36  ab
 GFYA     6.97 0.159 35.0     6.52     7.42   b
 FYA      7.08 0.159 35.0     6.62     7.53   b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05
```

Mixed-Model ANOVA of Degree of Overall Texture Scores

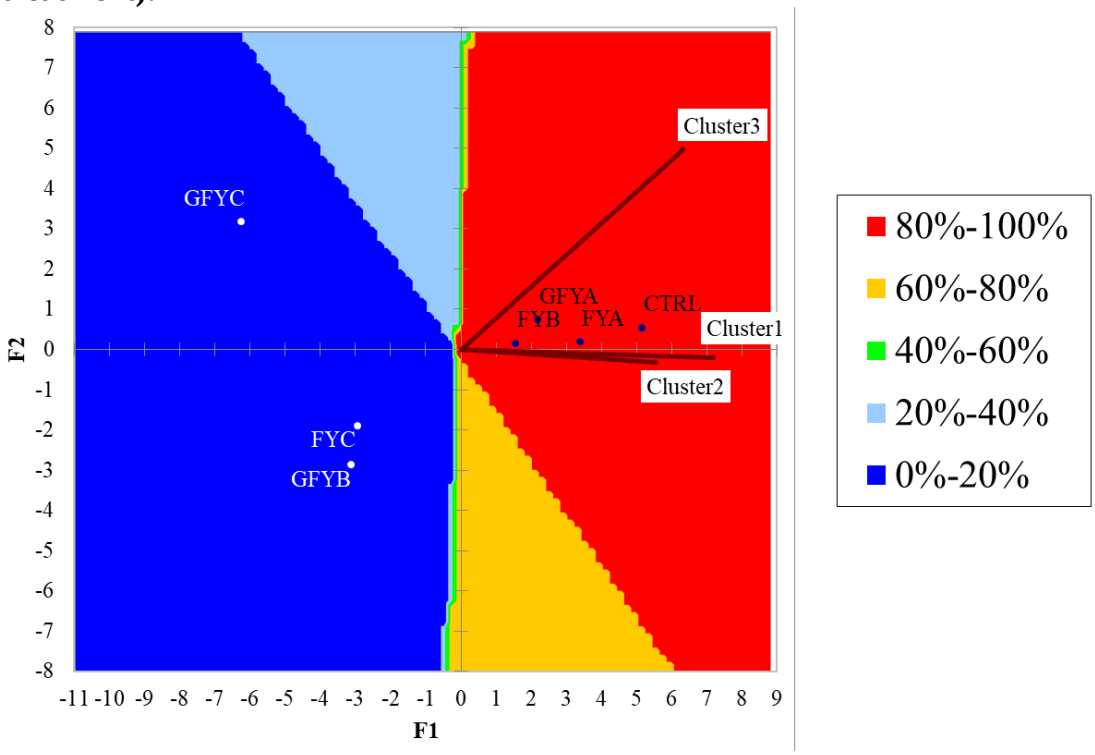
```
Type III Analysis of Variance Table with Satterthwaite's method
       Sum Sq Mean Sq NumDF  DenDF F value    Pr(>F)
Sample 115.89  19.314     6 37.019  7.2121 3.788e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
ANOVA-like table for random-effects: Single term deletions

Model:
DOT ~ Sample + (1 | Panel) + (1 | Sample:Panel)
                    npar  logLik    AIC    LRT Df Pr(>Chisq)
<none>                10 -1365.4 2750.7
(1 | Panel)            9 -1365.7 2749.4 0.6623  1    0.41574
(1 | Sample:Panel)     9 -1367.6 2753.2 4.4880  1    0.03413 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

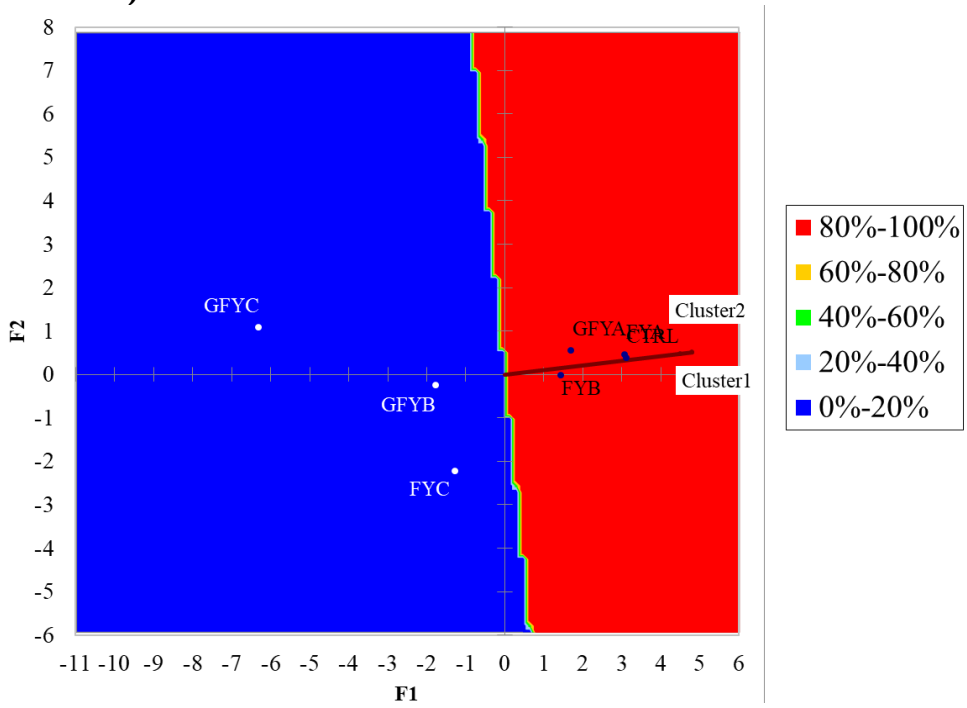
Degree of Overall Flavor Texture Statistics:

```
 Sample lsmean    SE   df lower.CL upper.CL .group
 GFYB     5.76 0.215 40.3     5.16     6.37  a
 GFYC     6.47 0.215 40.3     5.87     7.08  ab
 FYC      6.66 0.215 40.3     6.05     7.26  ab
 CTRL     7.01 0.215 40.3     6.40     7.62   b
 GFYA     7.12 0.215 40.3     6.51     7.72   b
 FYB      7.21 0.215 40.3     6.60     7.81   b
 FYA      7.37 0.215 40.3     6.76     7.97   b

Degrees-of-freedom method: kenward-roger
Confidence level used: 0.95
Conf-level adjustment: sidak method for 7 estimates
P value adjustment: tukey method for comparing a family of 7 estimates
significance level used: alpha = 0.05
```

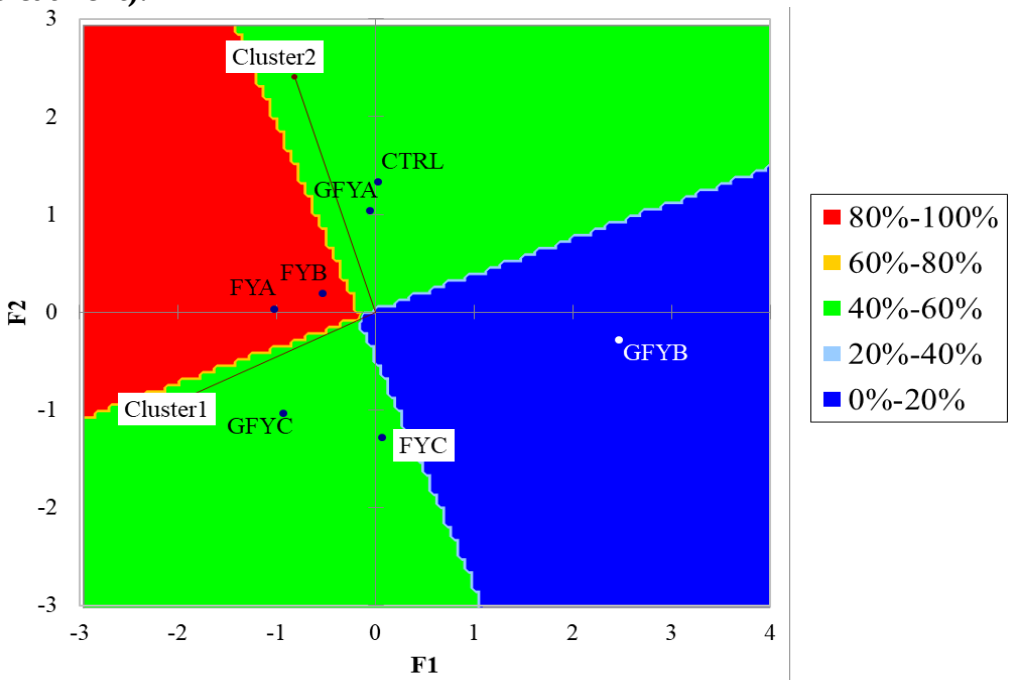
External preference map (XLSTAT) of consumer perception of overall liking with contour heat map (% range = percentage of panelists that preferred each treatment):



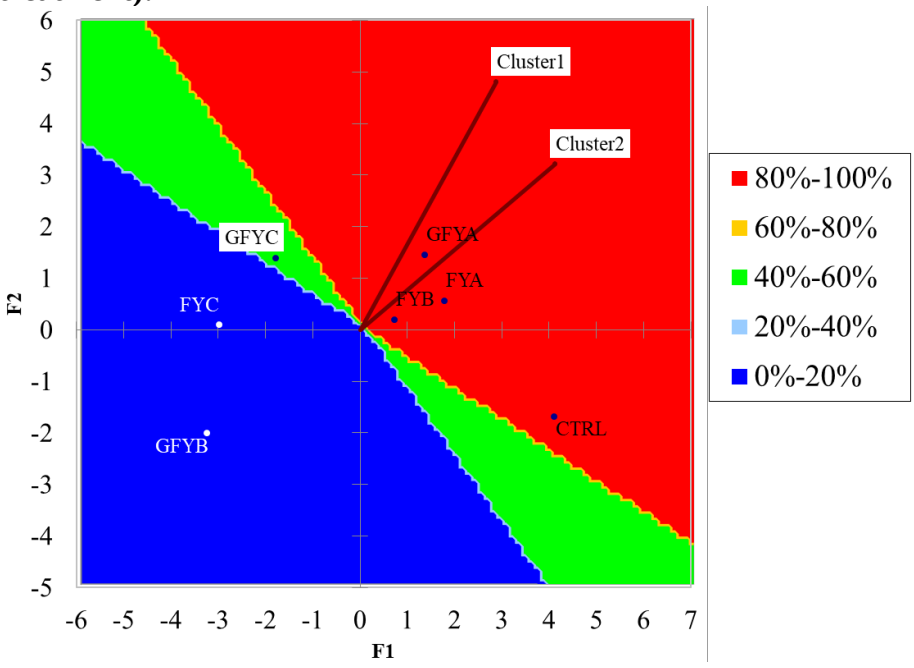
External preference map (XLSTAT) of consumer perception of flavor liking with contour heat map (% range = percentage of panelists that preferred each treatment):



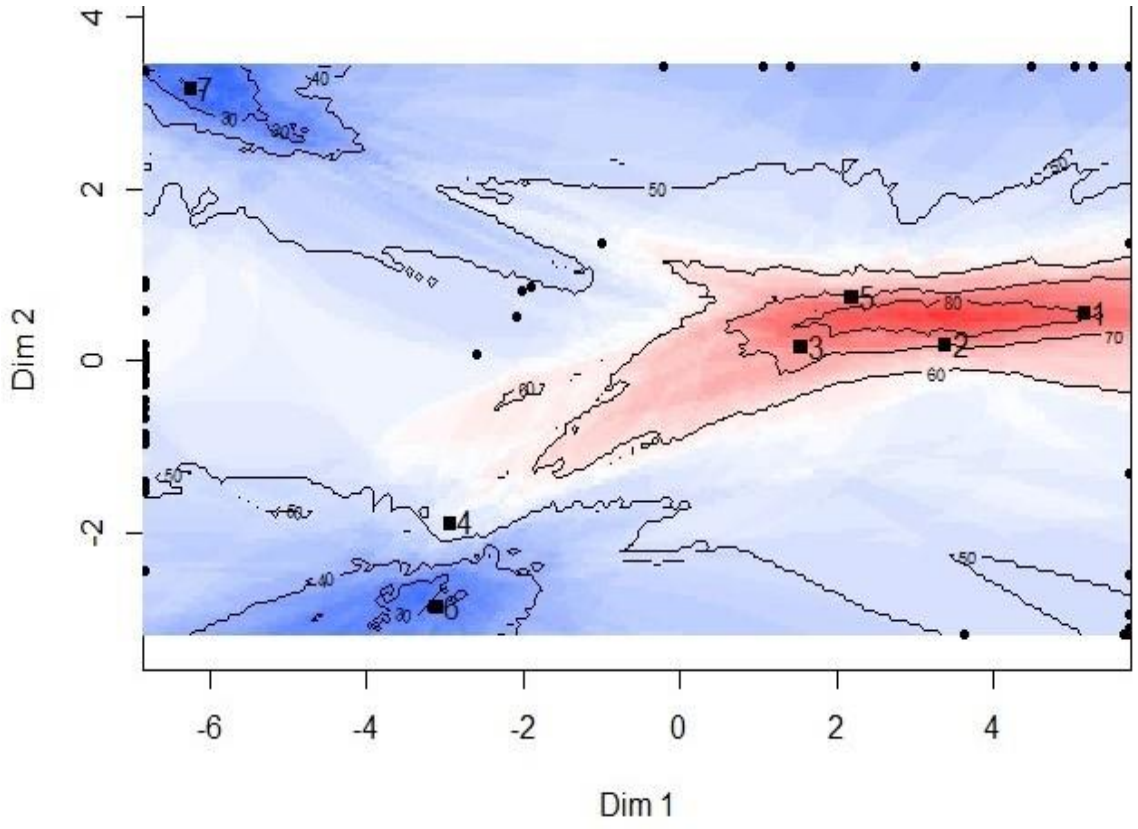
External preference map (XLSTAT) of consumer perception of appearance liking with contour heat map (% range = percentage of panelists that preferred each treatment):



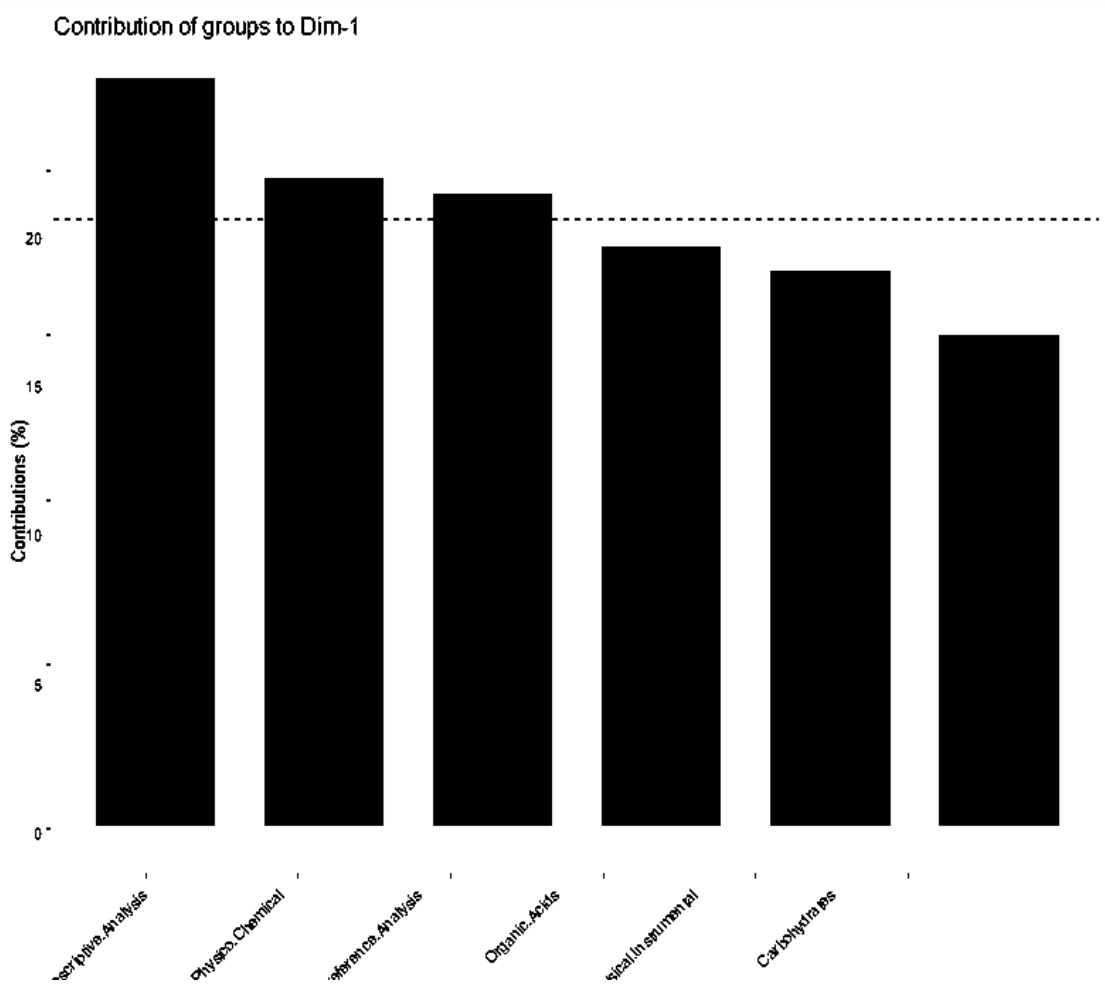
External preference map (XLSTAT) of consumer perception of texture liking with contour heat map (% range = percentage of panelists that preferred each treatment):

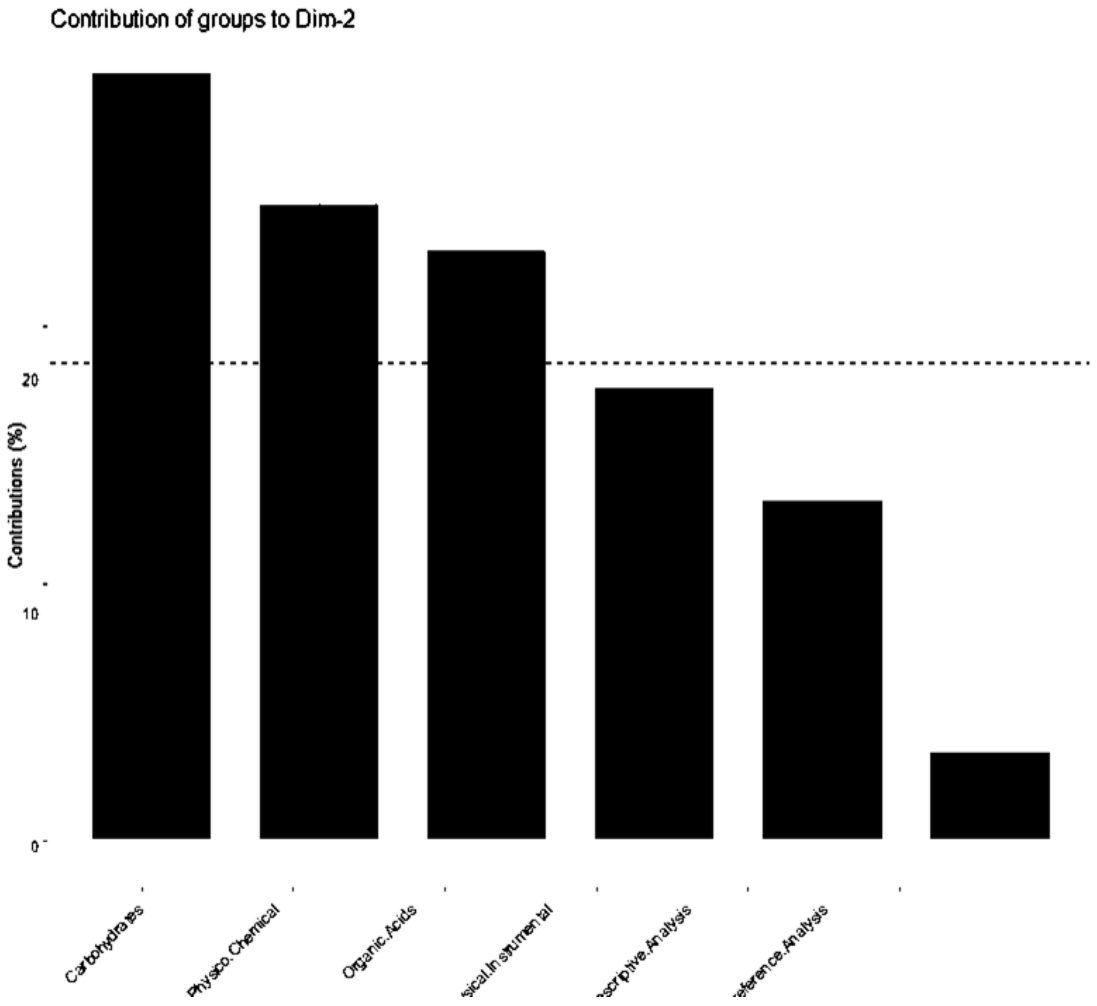


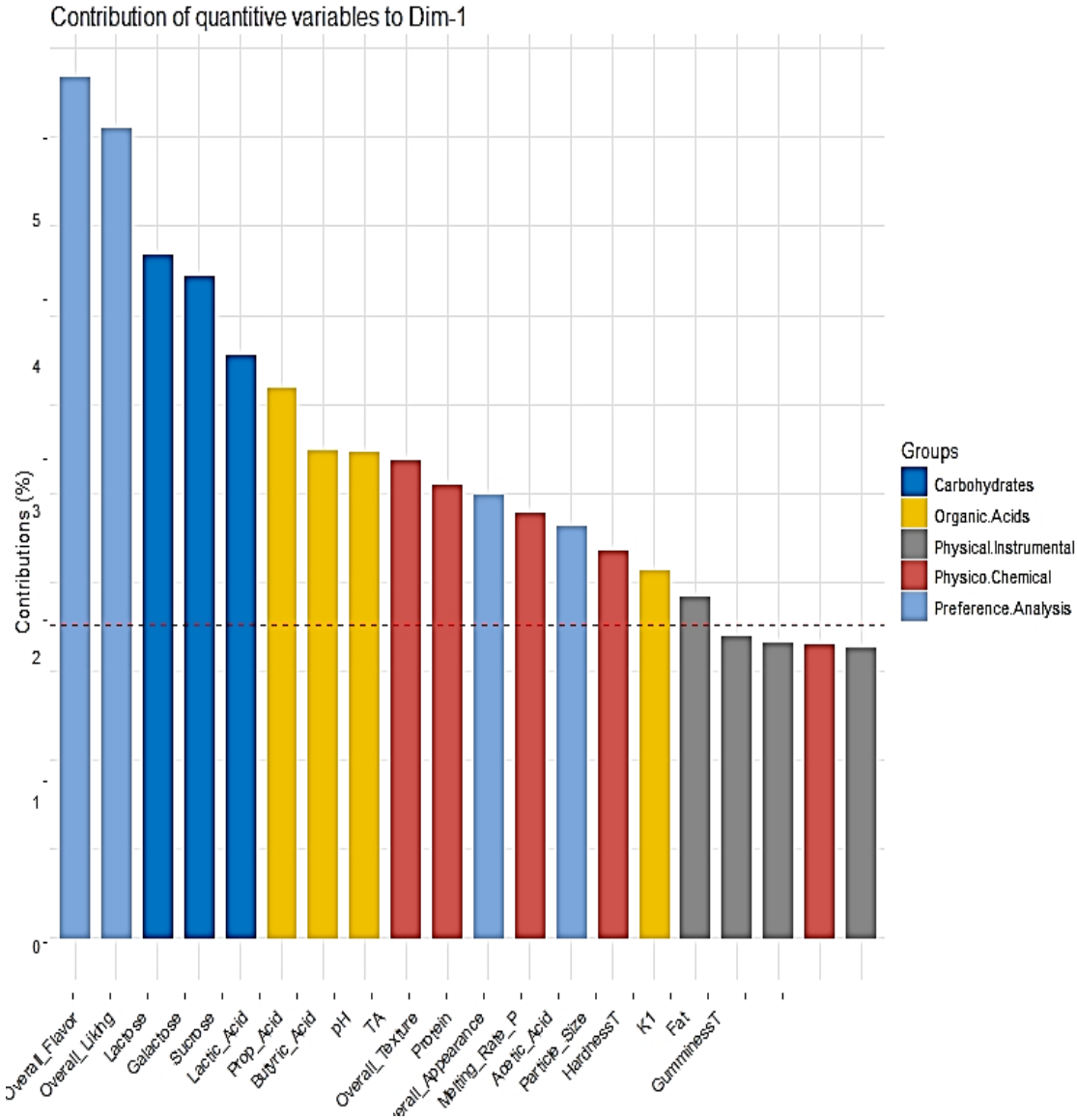
Preference Map (SensoMineR) without PCA Loadings:

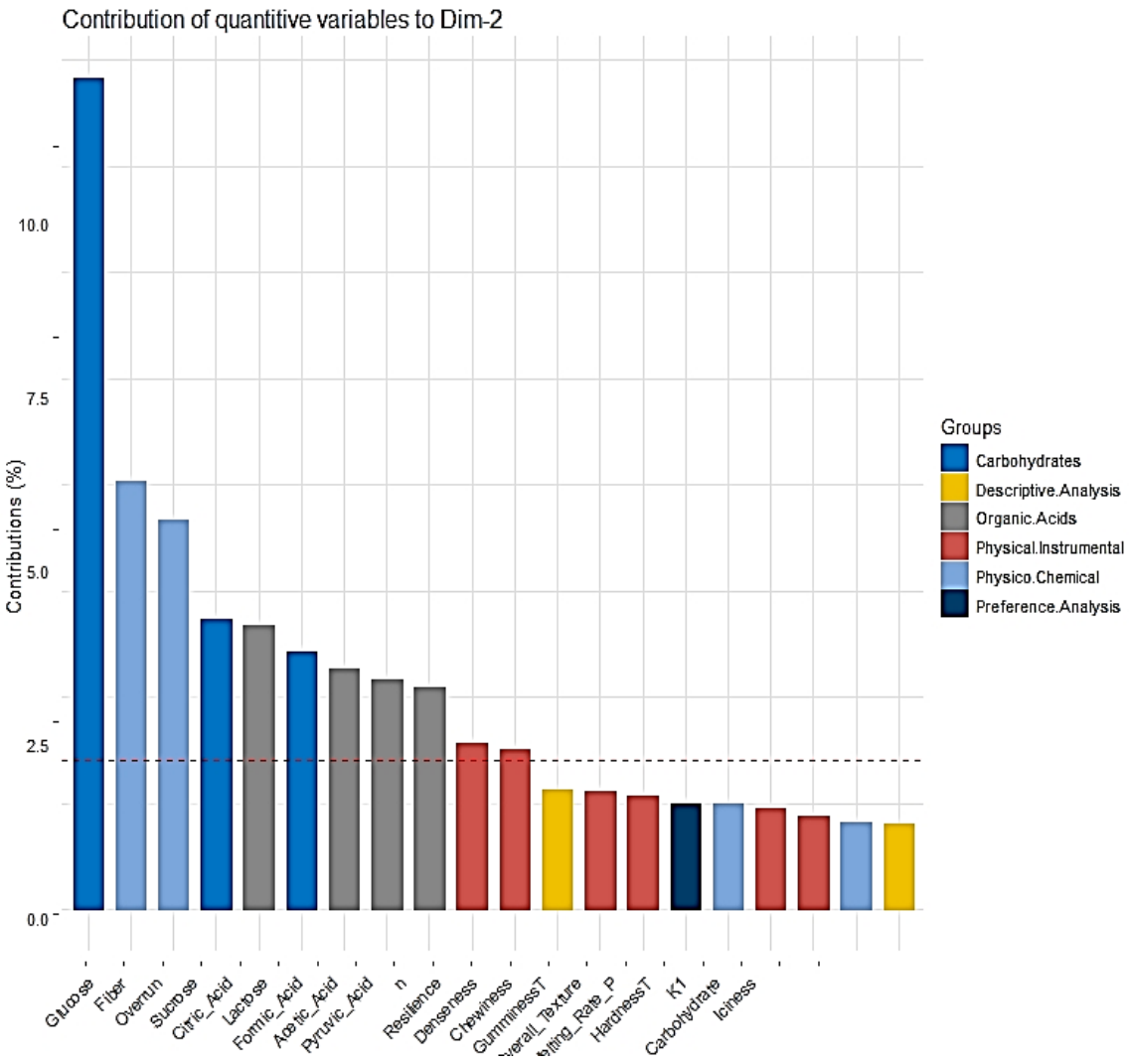


Appendix I – Multiple Factor Analysis Extra Materia




Contribution of groups to Dim-2
Contributions (%)
20
10
0
Carbohydrates
Physico.Chemical
Organic.Acids


Contribution of quantitive variables to Dim-1
Contributions (%)
0
1
2
4
5
Groups
Carbohydrates
Organic.Acids
Physical.Instrumental
Physico.Chemical
Preference.Analysis
Overall_Flavor
Overall_Liking
Lactose
Galactose
Sucrose
Lactic_Acid
Prop_Acid
Butyric_Acid
pH
TA
Overall_Texture
Protein
Melting_Rate_P
Acetic_Acid
Particle_Size
HardnessT
K1
Fat
GumminessT


Contribution of quantitive variables to Dim-2
Contributions (%)
10.0
7.5
5.0
2.5
0.0
Glucose
Fiber
Overrun
Sucrose
Citric_Acid
Lactose
Formic_Acid
Acetic_Acid
Pyruvic_Acid
n
Resilience
Denseness
Chewiness
GumminessT
Overall_Texture
Setting_Rate_P
HardnessT
K1
Carbohydrate
Iciness
Groups
Carbohydrates
Descriptive.Analysis
Organic.Acids
Physical.Instrumental
Physico.Chemical
Preference.Analysis

Appendix J – R-Code

One-Way ANOVA:

```
my_data <- "Loaded data set name"
my_data$Sample
class(my_data$Sample)
my_data$Sample <- as.factor(my_data$Sample)

#### ANOVA check #####
aov.out <- aov(TA ~ Sample, my_data)
summary(aov.out)

#### Orthogonal contrasts #####
Yogurt_Type <- c(0,1,1,1,-1,-1,-1)
Concentration_10_15 <- c(0,1,-1,0,1,-1,0)
Concentration_10_20 <- c(0,1,0,-1,1,0,-1)
Linear_Contrast_Int <- c(0,-1,0,1,1,0,-1)
Quadratic_Contrast_Int <- c(0,1,-2,1,-1,2,-1)

#### one-Way ANOVA with orthogonal contrasts loaded###
aov.out <- aov(TA ~ Sample, my_data)
summary(aov.out)
(full_summary <-
summary.aov(aov.out,split=list(Sample=list("Yogurt_Type"=1,"Concentration_10_15"=2
,"Concentration_10_20"=3,"Concentration_15_20"=4,"Contrast_Linear"=5,"Contrast_Qu
adratic"=6))))

###Post-hoc Analysis###
tukey.test2 <- HSD.test(aov.out,trt = 'Sample')
tukey.test2
```

mixed-model ANOVA

###Libraries###

Library(lme4)	Library(lsmeans)	Library(Pbkrtest)	Library(multcomp)
Library(matrix)	Library(emmeans)	Library(lmerTest)	Library(agricolae)

```
#### mixed-model ANOVA#####
model = lmer(DOL ~ Sample + (1|Panel) + (1|Sample:Panel),
             data=my_data,
             REML=TRUE)

anova(model)
rand(model)

###Post-Hoc Analysis###
CLD = cld(marginal,
          alpha=0.05,
          Letters=letters,
          adjust="tukey")

CLD
```

Pearson Correlation

```
res <- cor(my_data)
round(res, 2)

cor(my_data, use = "complete.obs")
rcorr("DOL", type = c("pearson","spearman"))
res2 <- rcorr(as.matrix(my_data))
res2
res2$r
res2$P

res2<-rcorr(as.matrix(my_data))
flattenCorrMatrix(res2$r, res2$P)

symnum(res, abbr.colnames = FALSE)
corrplot(res, type = "upper", order = "hclust",
         tl.col = "black", tl.srt = 45)
```

Clustering Methods (For AHC method in the PREFMAP (XLSTAT)

```
##Load data##
my_data <- Internal_Preference_Mapping
head(my_data)
my_data$Sample
my_data$Sample <- as.numeric(my_data$Sample)


# subset dataset
dsc <- my_data
dsc <- my_data %>% select(-PanelistA) # set rownames
dsc <- as_tibble(dsc)

# Glimpse the data set
glimpse(dsc)

# Summary of data set
summary(dsc) %>% kable() %>% kable_styling()

corrplot(cor(dsc), type = "upper", method = "ellipse", tl.cex = 0.9)

#PCA
dsc_scaled <- scale(dsc)
rownames(dsc_scaled) <- my_data$PanelistA

res.pca <- PCA(dsc_scaled,  graph = FALSE)
# Visualize eigenvalues/variances
fviz_screeplot(res.pca, addlabels = TRUE, ylim = c(0, 50))

# Extract the results for variables
var <- get_pca_var(res.pca)
# Contributions of variables to PC1
fviz_contrib(res.pca, choice = "var", axes = 1, top = 10)
# Contributions of variables to PC2
fviz_contrib(res.pca, choice = "var", axes = 2, top = 10)
# Control variable colors using their contributions to the principle axis
fviz_pca_var(res.pca, col.var="contrib",
             gradient.cols = c("#00AFBB", "#E7B800", "#FC4E07"),
             repel = TRUE # Avoid text overlapping
) + theme_minimal() + ggtitle("Variables - PCA")


# function to compute total within-cluster sum of squares
fviz_nbclust(dsc_scaled, kmeans, method = "wss", k.max = 24) + theme_minimal() +
ggtitle("the Elbow Method")
```

```
##gap method##
gap_stat <- clusGap(dsc_scaled, FUN = kmeans, nstart = 30, K.max = 24, B = 50)
fviz_gap_stat(gap_stat) + theme_minimal() + ggtitle("fviz_gap_stat: Gap Statistic")

##silhouette method##
fviz_nbclust(dsc_scaled, kmeans, method = "silhouette", k.max = 24) + theme_minimal()
+ ggtitle("The Silhouette Plot")


#ncblast method###
res.nbclust <- NbClust(dsc_scaled, distance = "euclidean",
                  min.nc = 2, max.nc = 9,
                  method = "complete", index ="all")
factoextra::fviz_nbclust(res.nbclust) + theme_minimal() + ggtitle("NbClust's optimal
number of clusters")

# Compute dissimilarity matrix with euclidean distances
 d <- dist(dsc_scaled, method = "euclidean")

# Hierarchical clustering using Ward's method
res.hc <- hclust(d, method = "ward.D2" )

# Cut tree into 5 groups (or how ever many clusters are fit for your data set###
grp <- cutree(res.hc, k = 10)

# Visualize
plot(res.hc, cex = 0.6) # plot tree
rect.hclust(res.hc, k = 5, border = 2:5) # add rectangle

# Execution of k-means with k=2
final <- kmeans(dsc_scaled, 2, nstart = 30)
fviz_cluster(final, data = dsc_scaled) + theme_minimal() + ggtitle("k = 2")
```

Vita

Yanni Bullock was born in Berkeley, California. He was the first son in his family to leave home for college before his three siblings. He was awarded a Bachelor of Science degree in Biological Sciences with a concentration in Cellular and Molecular Biology and a minor in Chemistry from California State University, California in 2017. In the fall 2017, he was admitted into the University of Missouri – Columbia Food Science program and pursued his Doctorate in Food Science. After completing his core responsibilities and earning multiple scholarships from the *IFT St. Louis Section* and the *Robert T. Marshall Award*, he received his Doctoral degree in the year of 2021 with a minor in College Teaching.